Department of Radiology
UNIVERSITY OF WISCONSIN
SCHOOL OF MEDICINE AND PUBLIC HEALTH

UW IMAGE-GUIDED INTERVENTIONS LAB

A Comprehensive Guide to Interventional CT: Technology, Workflow, and Dose Considerations

Martin Wagner, PhD

Slides partially courtesy of **Timothy Szczykutowicz**

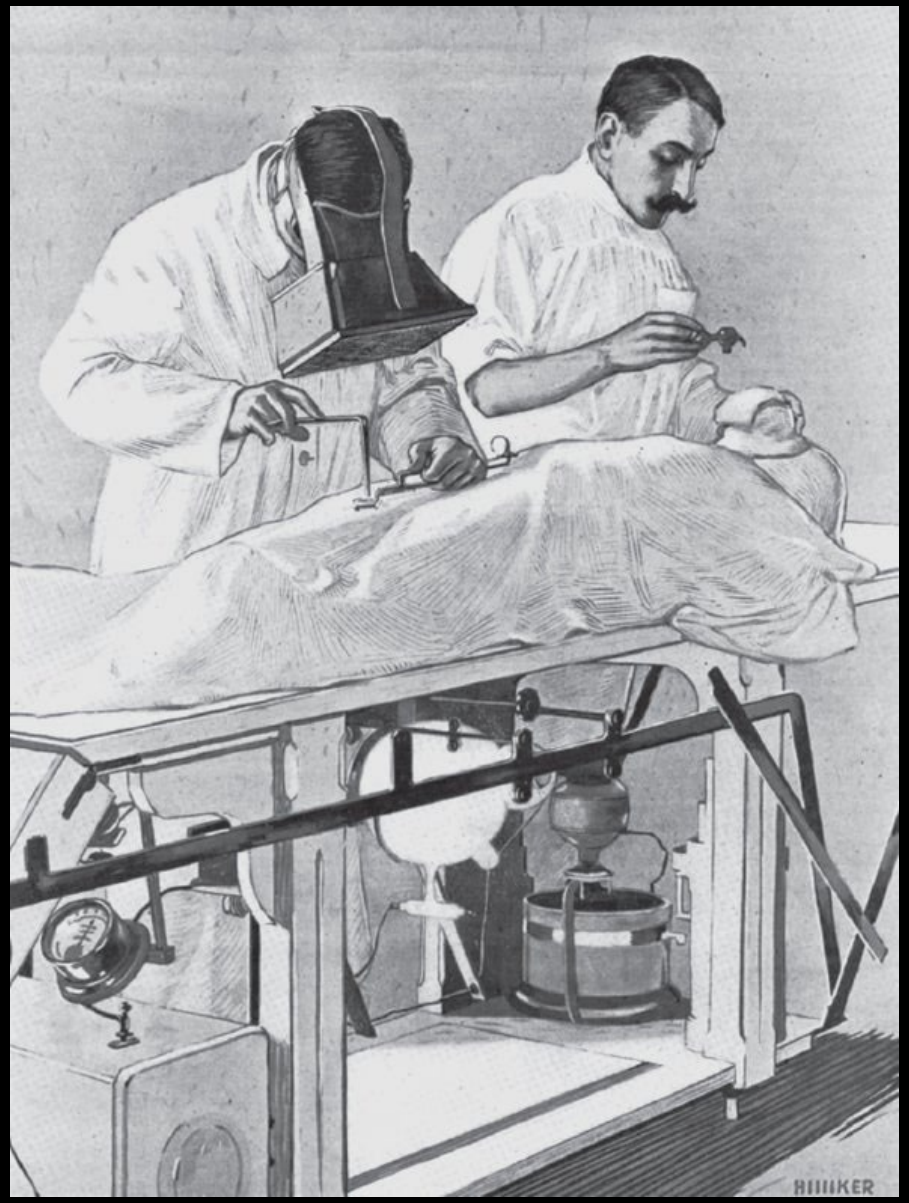
Disclosures

- Consultant for HistoSonics Inc.
- Sponsored research agreements with
  - Siemens Healthineers
  - Canon Medical
  - HistoSonics Inc.

Outline

1. **What is Interventional CT?**
2. High level scheduling considerations
3. Scanner Options Overview
4. Interventional CT Specific Options
5. Dose
6. Advanced Device Guidance
7. Ongoing Research

History

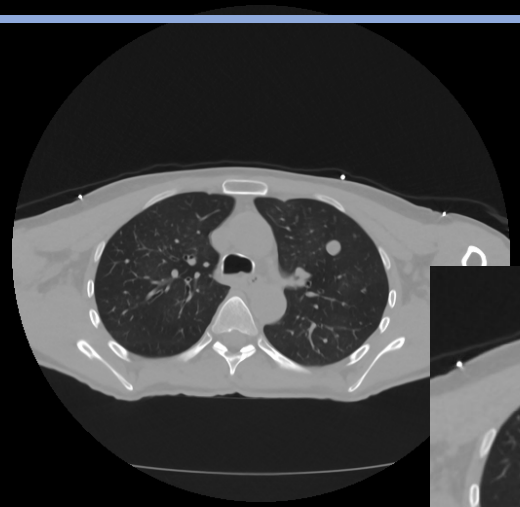


1916: Surgery performed with the help of x-rays. Credit: Scientific American Supplement, VOL. LXXXI, NO. 2110; June 10, 1916

Interventional CT Guidance Overview

Some prior imaging where we identify the need for a biopsy or ablation/treatment intervention

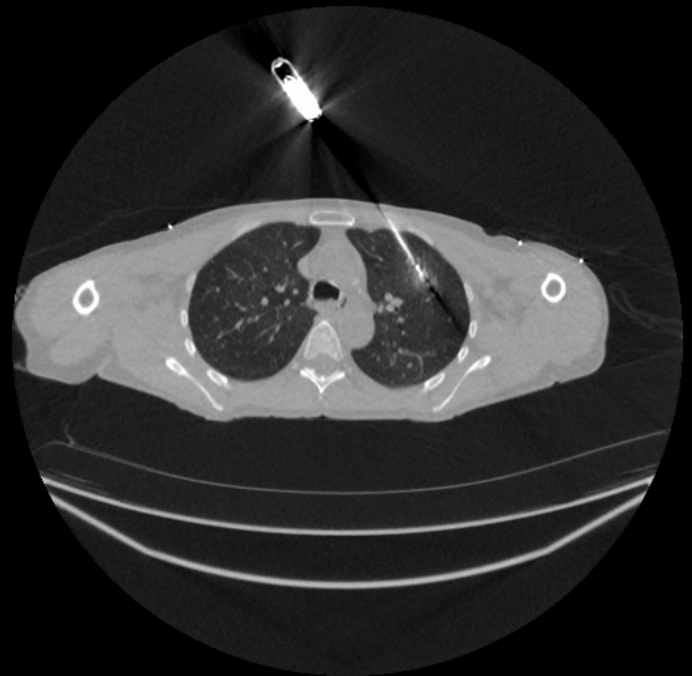
Procedural imaging



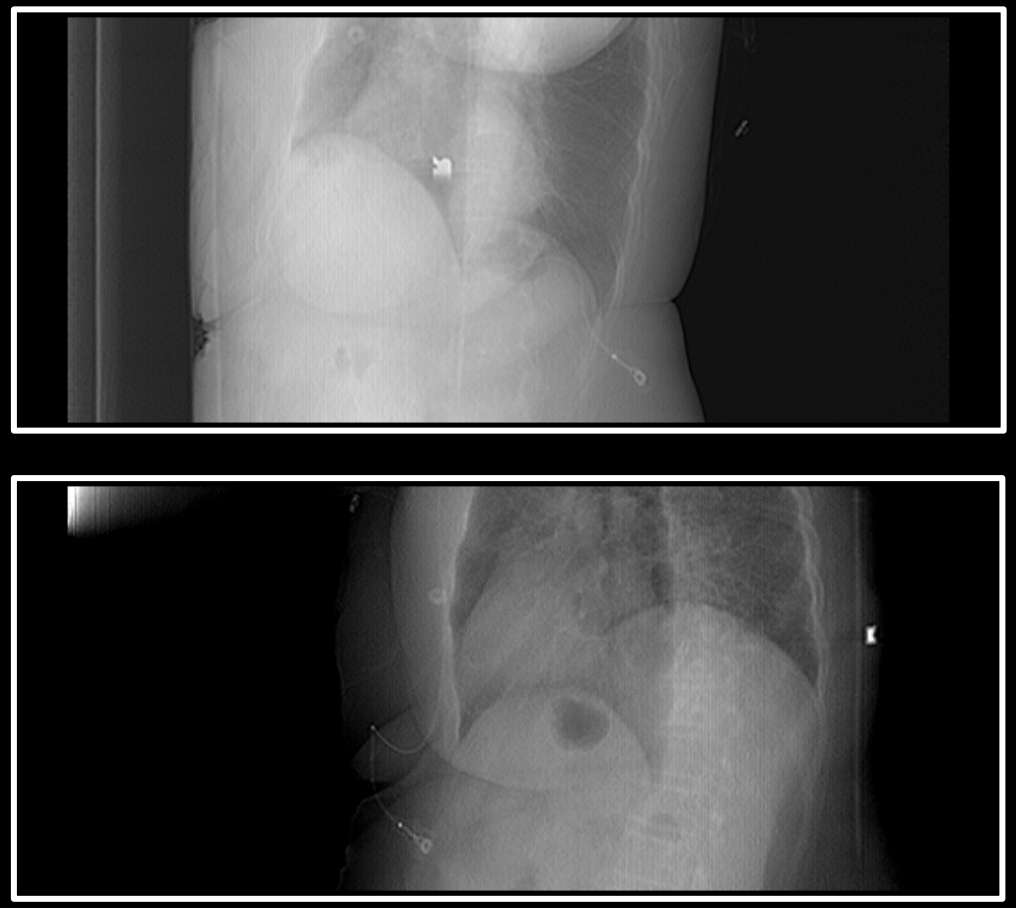
Day of planning

Trajectory planning

Imaging to make sure device is heading towards target, imaging to ensure device hits target



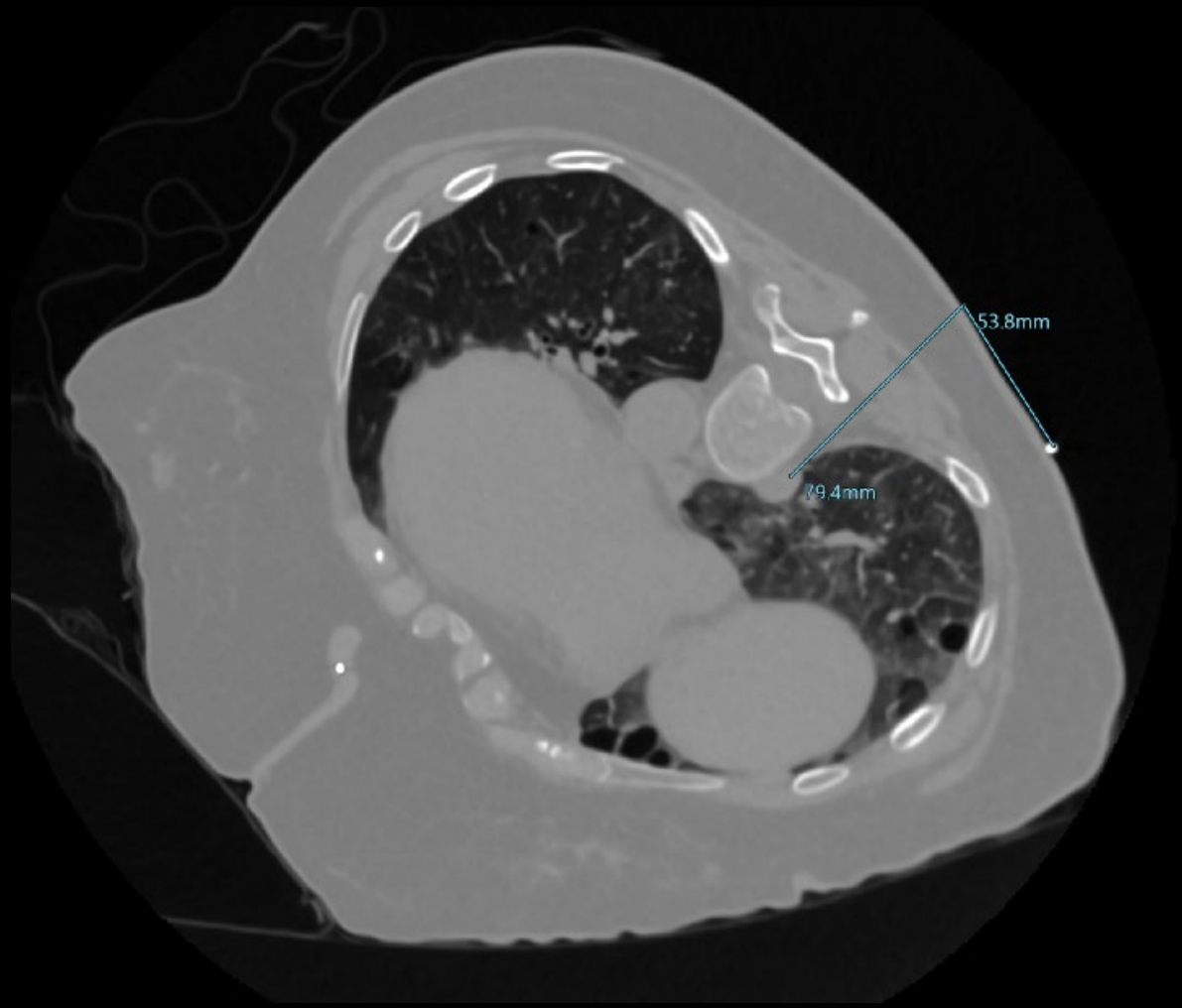
Overview of an interventional CT procedure



1. Scout patient like we do in dx imaging

2. Plan and acquire a “planning volume” i.e., a “regular helical CT” as is done in dx imaging

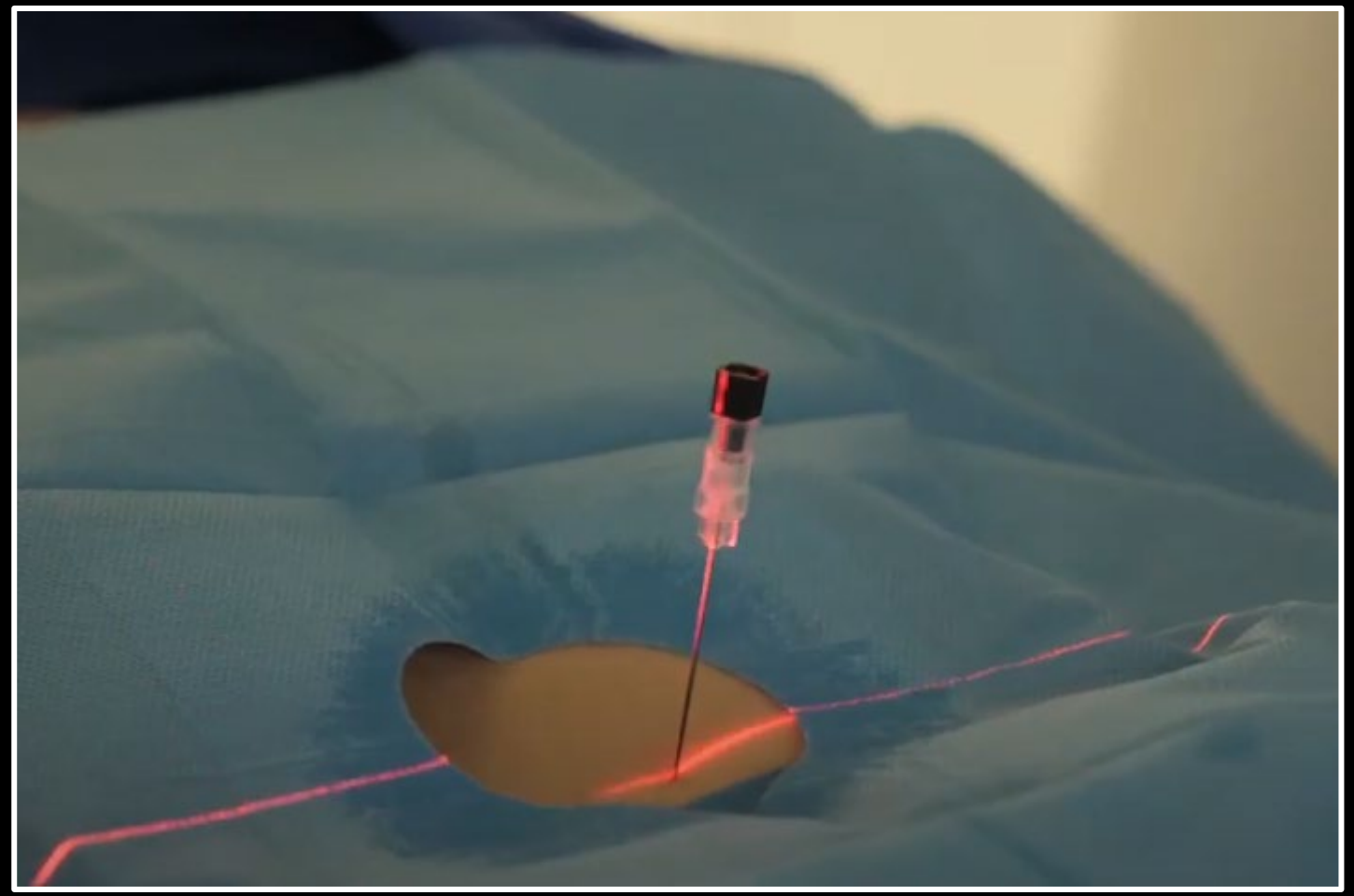
Overview of an interventional CT procedure



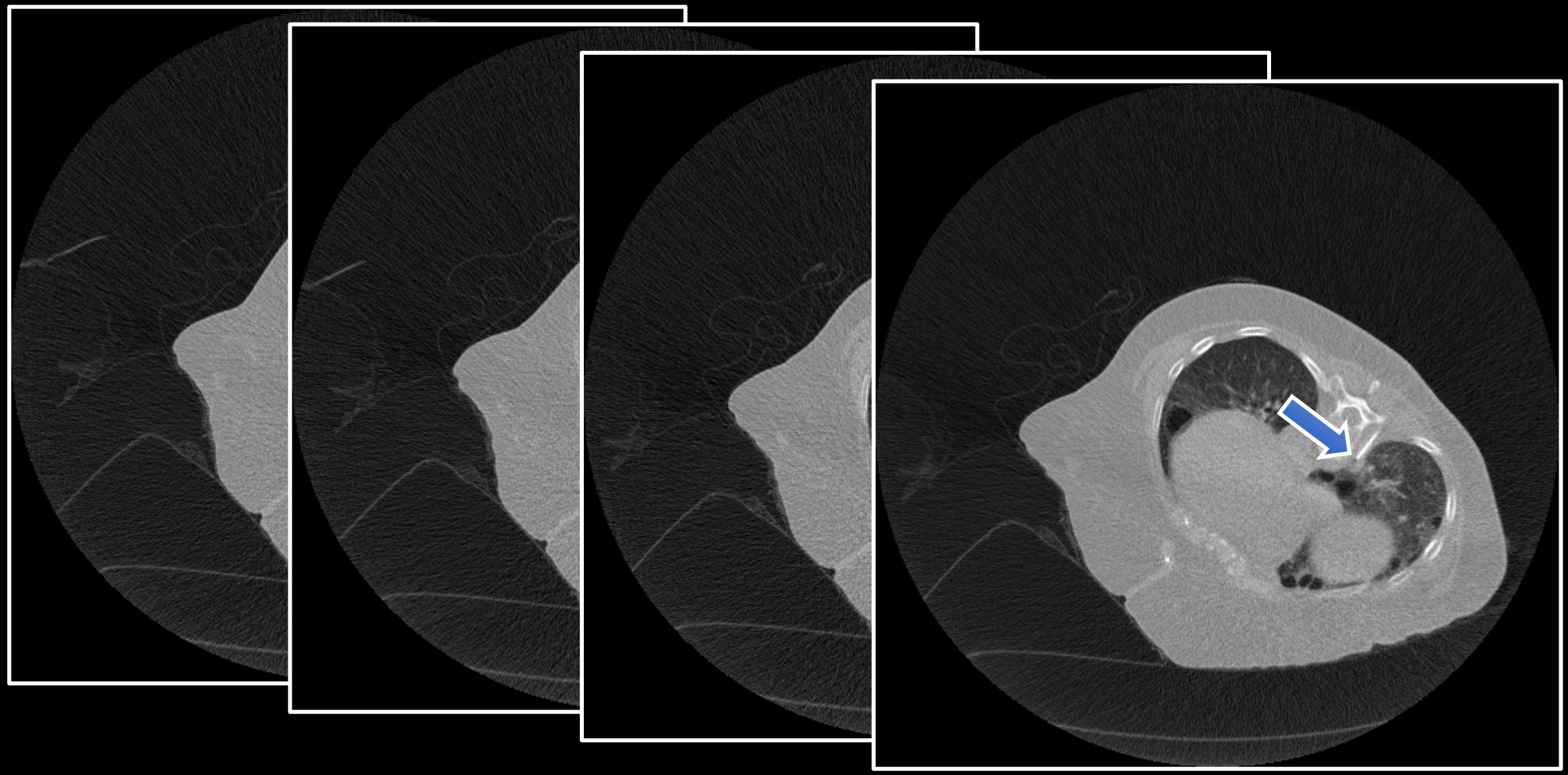
3. Interventional physician reviews planning volume and picks target slice locations and plans trajectory

Overview of an interventional CT procedure

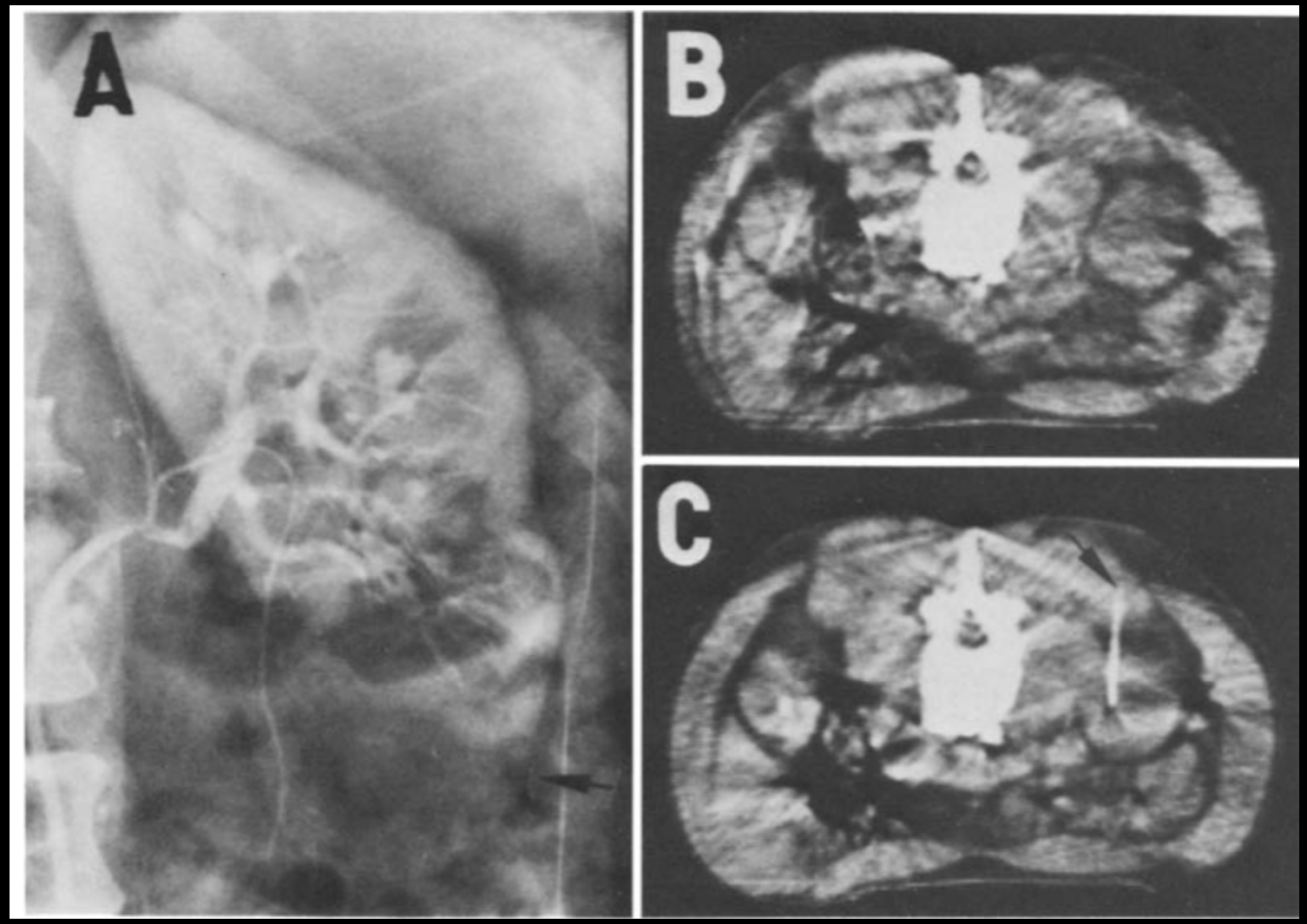
4. Interventional physician performs initial puncture and aligns needle with the planned trajectory

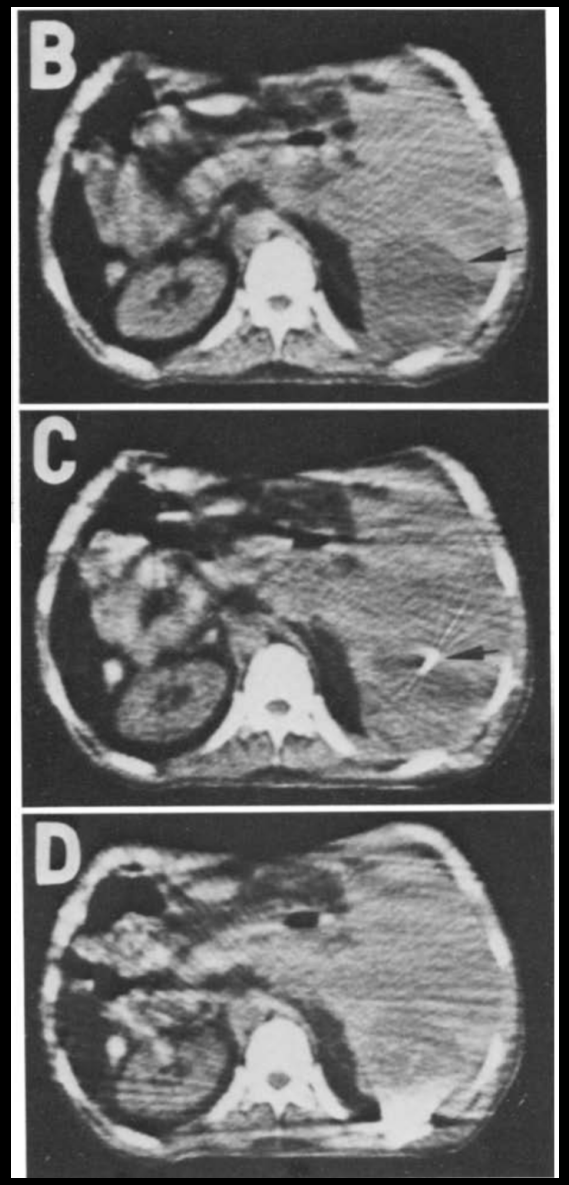


Overview of an interventional CT procedure



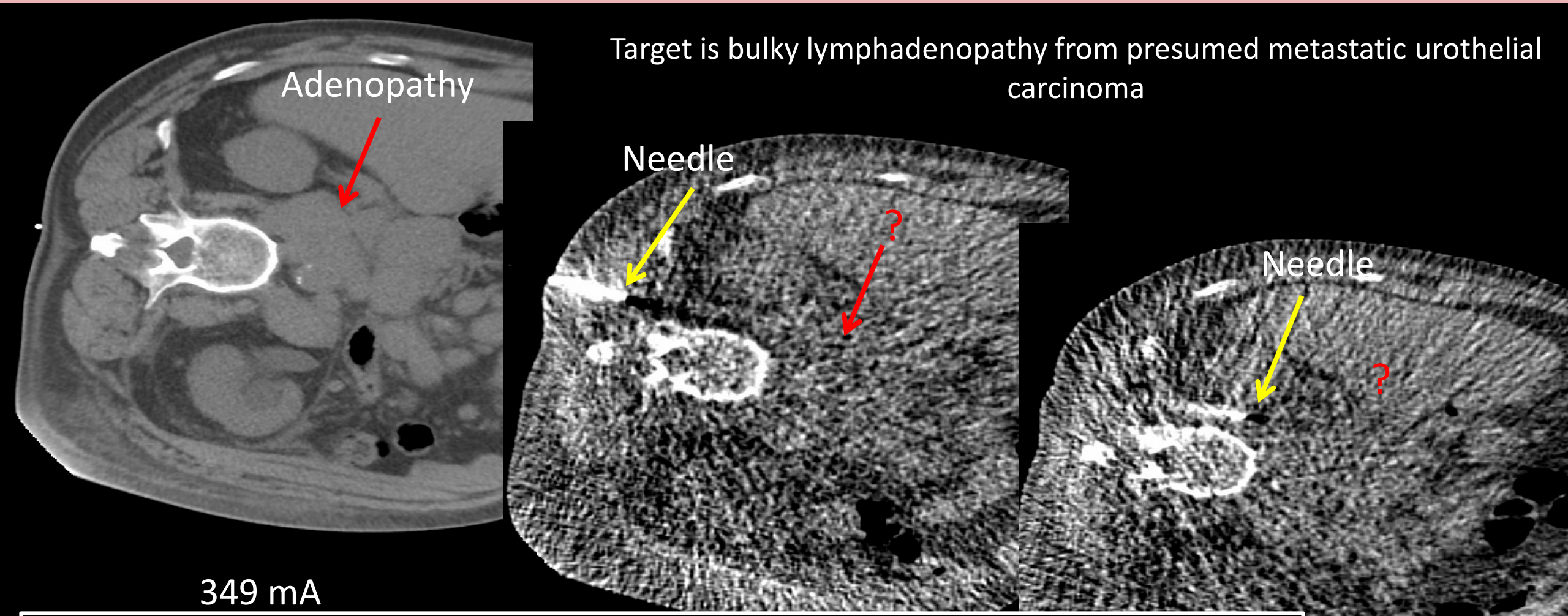
Haaga Method





Haaga J, Alfidi R, Radiology 1976;118

CT Fluoroscopy: Image Quality



CTF images are so noisy and artifact laden, one often cannot see the target!

Percutaneous Biopsies

Percutaneous biopsy in the abdomen and pelvis: a step-by-step approach

George A. Carberry,[1,2] Meghan G. Lubner,[1] Shane A. Wells,[1]

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[2]Department of Radiology, University of Wisconsin School of Medicine and Public Health, Highland Ave., Madison, WI 53792-3252, USA

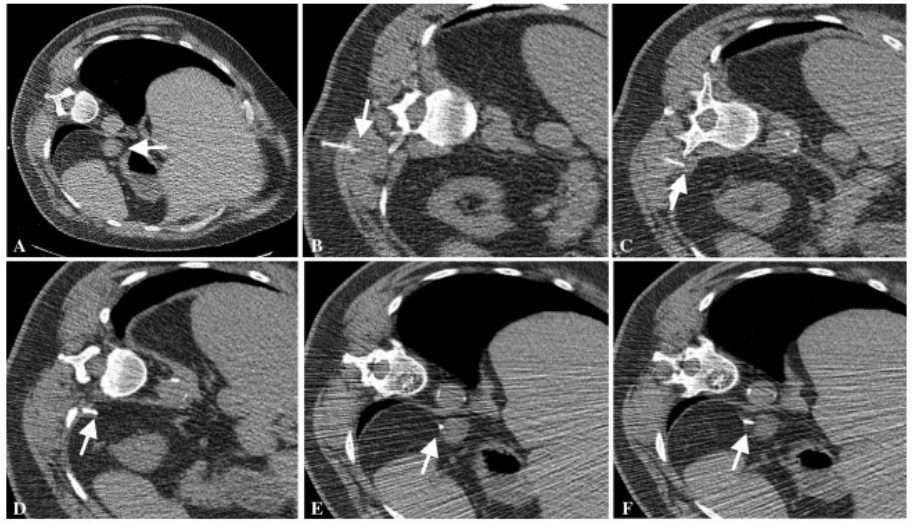
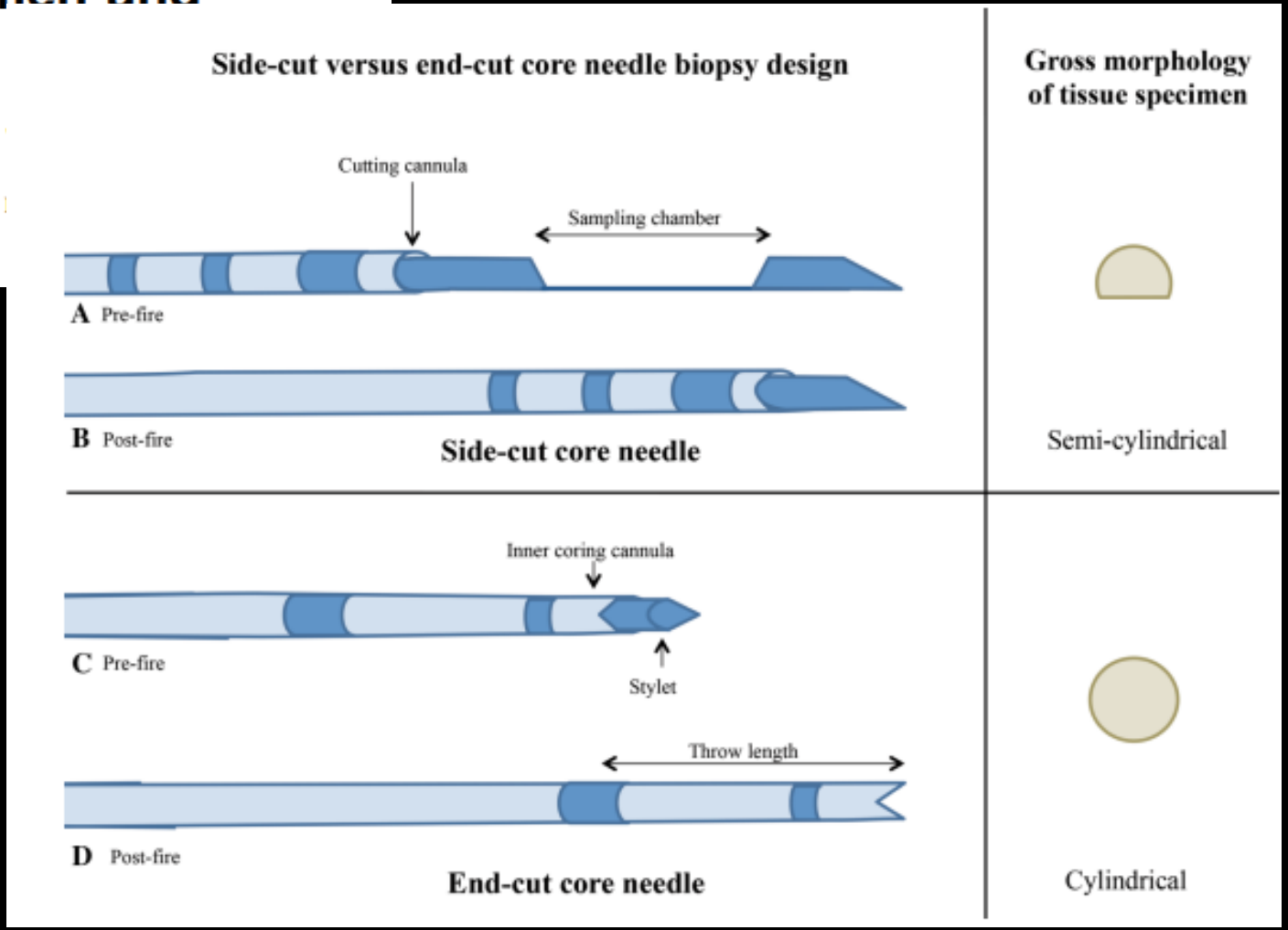
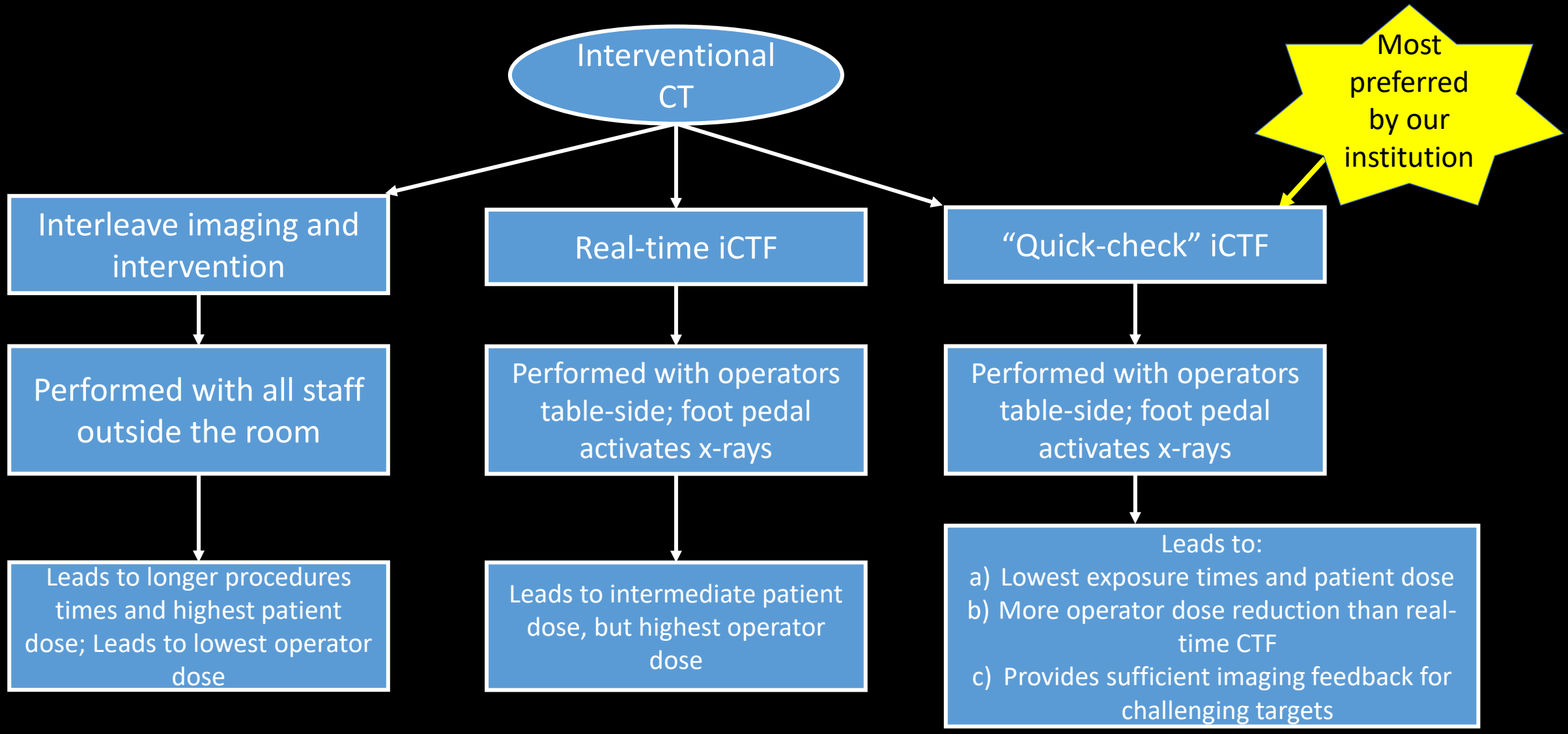


Fig. 7. Use of the "dead reckoning" technique to safely biopsy an indeterminate adrenal nodule. Transverse unenhanced pre-procedure CT image (**A**) demonstrates lung in the projected needle path to the left adrenal nodule (*arrow*) despite left lateral decubitus positioning of the patient. An axial slice several centimeters caudal to the lesion (**B**) was selected for needle entry (*arrow* needle tip). Sequential CT fluoroscopic images (**C**–**F**) demonstrate progressive advancement of the needle in the cephalad direction, keeping only the tip of the needle (*arrow*) in the axial plane with the CT table adjustments. Image (**F**) demonstrates the needle tip in the target lesion without traversing the lung. This can be a very technically challenging biopsy method.



Overview of interventional CT practices



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Interventional CT…more people, more room prep, longer exams, longer room turn over.

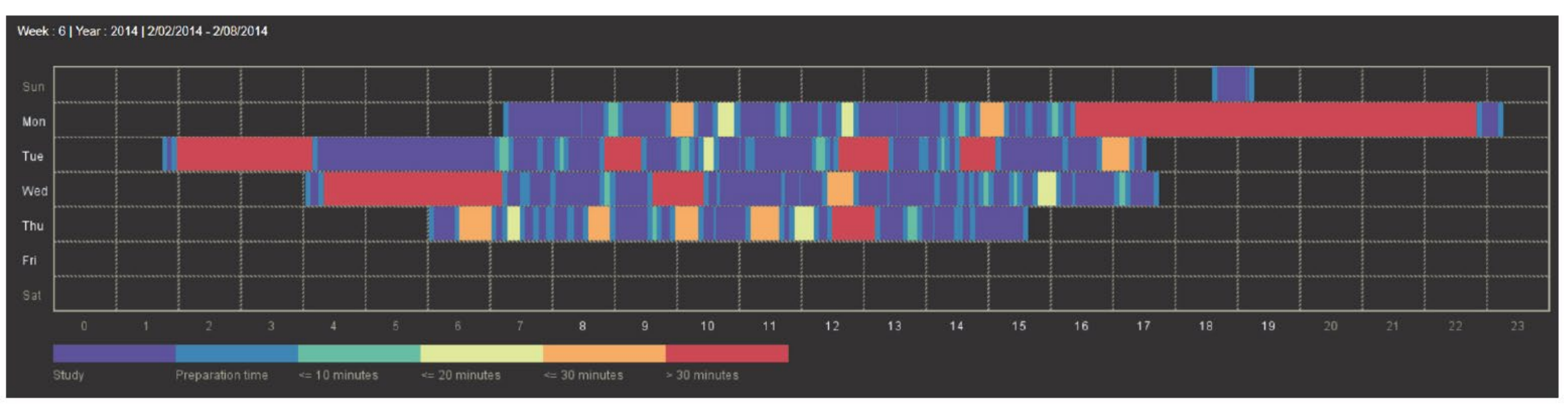
Interventional CT

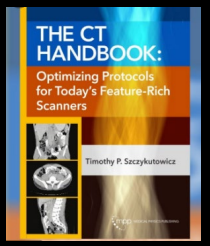
- Usually 1-2 CT techs, 1-2 radiologists, 1-2 people for sedation/anesthesia, 1 nurse, 1 sonographer.
- Supplies for interventional device, supplies for EM navigation, contrast supplies, lines, sterile trays, way more PPE than dx imaging on everyone.

Diagnostic CT

- A single CT tech and linens. ~40% of the time→ contrast injector consumables.

Scheduling





Szczykutowicz, Timothy. *The CT Handbook: Optimizing Protocols for Today's Feature-rich Scanners*. Medical Physics Publishing, 2020

Scheduling

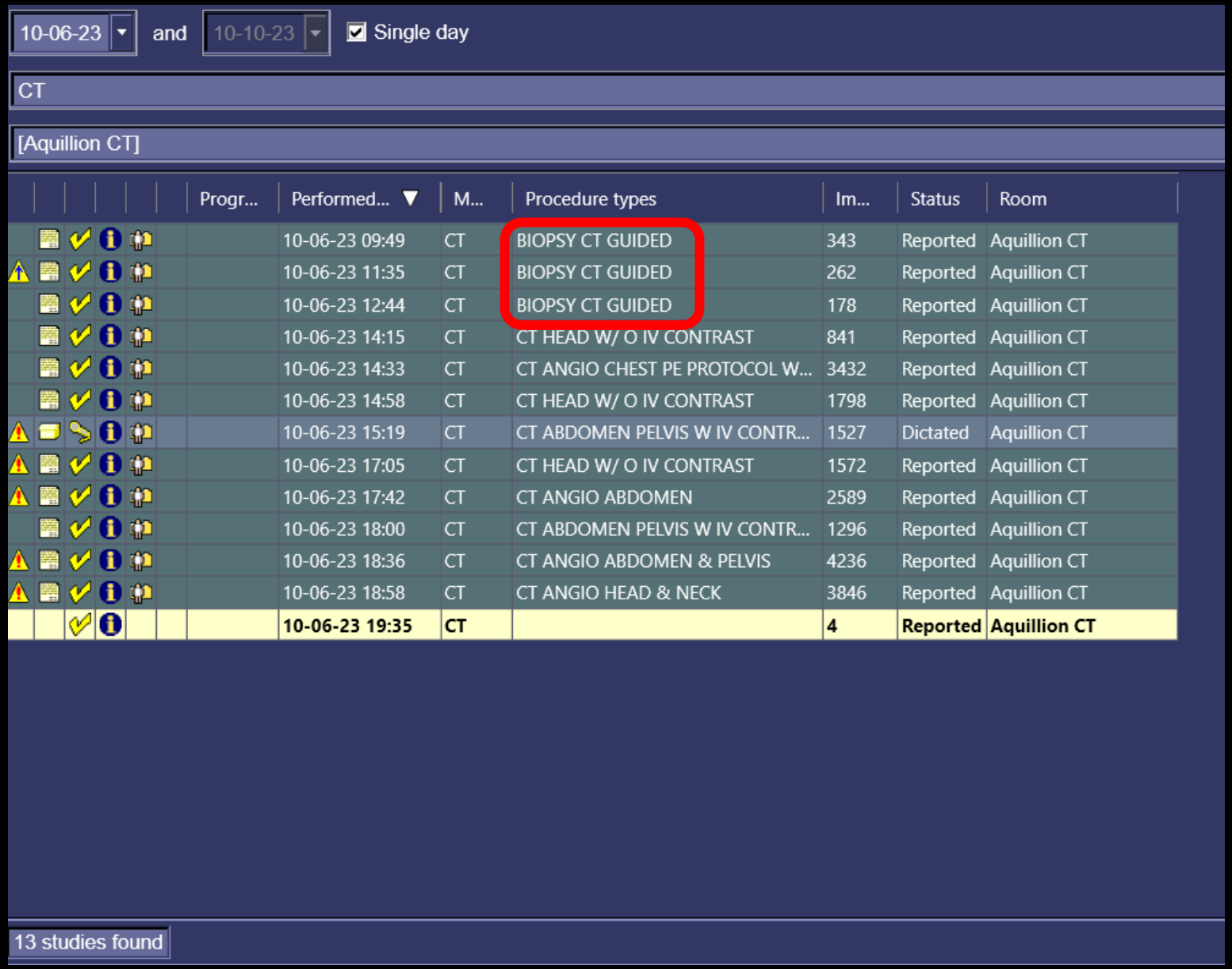
1 CT scanner, doing dx studies during the day, some after hours use as needed

Progr...	Performed on	M...	Procedure types	Im...	Status	Room
	10-03-23 21:35	CT	CT ANGIO CHEST PE PROTOCOL...	2173	Reported	Aquillion CT
	10-03-23 21:09	CT	CT ANGIO CHEST PE PROTOCOL W...	2216	Reported	Aquillion CT
	10-03-23 17:48	CT	CT ABDOMEN PELVIS W IV CONTR...	1463	Reported	Aquillion CT
	10-03-23 23:24	CT		5	Reported	Aquillion CT
	10-03-23 09:21	CT	CT NECK W IV CONTRAST	2503	Reported	Aquillion CT
	10-03-23 09:00	CT	CT HEAD W/ O IV CONTRAST	893	Reported	Aquillion CT
	10-03-23 22:05	CT	CT ANGIO CHEST PE PROTOCOL W...	2015	Reported	Aquillion CT
	10-03-23 15:23	CT	CT CHEST W/ O IV CONTRAST W/C...	3144	Reported	Aquillion CT
	10-03-23 20:41	CT	CT ABDOMEN PELVIS W IV CONTR...	1475	Reported	Aquillion CT
	10-03-23 19:01	CT	CT NECK W IV CONTRAST	2848	Reported	Aquillion CT
	10-03-23 10:10	CT	CT CERVICAL SPINE W/ O IV CONT...	1422	Reported	Aquillion CT
	10-03-23 10:07	CT	CT HEAD W/ O IV CONTRAST	1524	Reported	Aquillion CT
	10-03-23 10:55	CT	CT ABDOMEN PELVIS W IV CONTR...	1697	Reported	Aquillion CT
	10-03-23 10:51	CT	CT CHEST W/ O IV CONTRAST W/C...	2690	Reported	Aquillion CT
	10-03-23 10:46	CT	CT SINUS W/ O IV CONTRAST	1272	Reported	Aquillion CT
	10-03-23 16:36	CT	STROKE CODE-CT ANGIO HEAD NE...	4949	Reported	Aquillion CT
	10-03-23 12:00	CT	CT SINUS W/ O IV CONTRAST	1224	Reported	Aquillion CT
	10-03-23 15:56	CT	CT ANGIO CHEST PE PROTOCOL W...	2862	Reported	Aquillion CT
	10-03-23 19:35	CT	CT TRAUMA ABDOMEN PELVIS W I...	1650	Reported	Aquillion CT
	10-03-23 13:41	CT	CT ABDOMEN PELVIS W IV CONTR...	1631	Reported	Aquillion CT
	10-03-23 20:11	CT	CT ANGIO CHEST PE PROTOCOL W...	2386	Reported	Aquillion CT
	10-03-23 18:15	CT	CT ABDOMEN PELVIS W IV CONTR...	1394	Reported	Aquillion CT

Scheduling

1 CT scanner, AM biopsy, afternoon dx

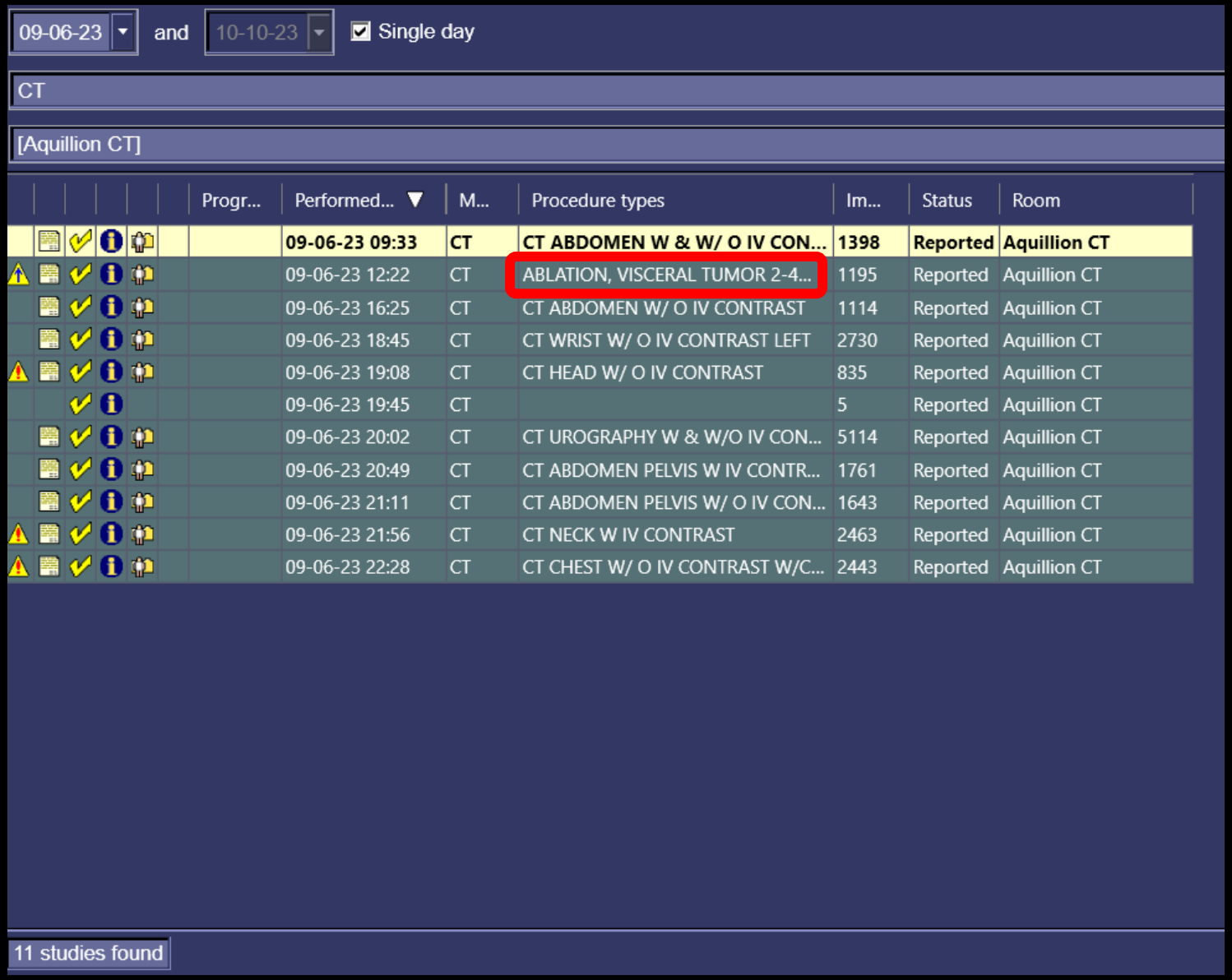
28 exams to 13



Scheduling

1 CT scanner,
1 ~4 hour ablation block

28 exams to 11



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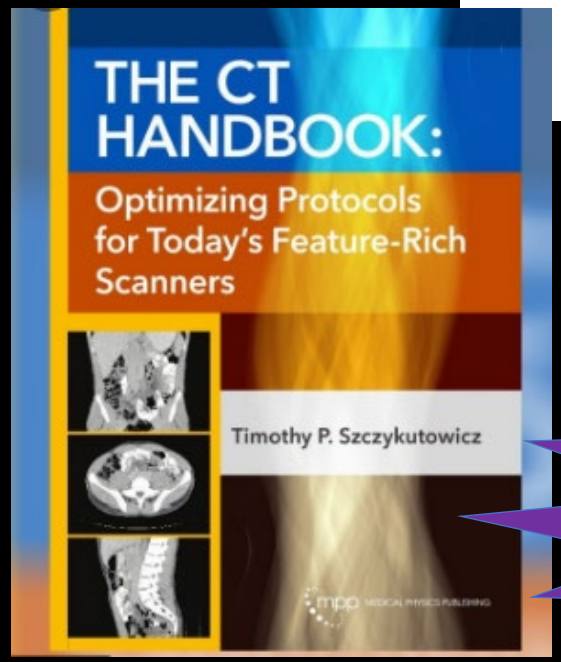
Resources for understanding purchasing decisions



ahra QUICK CREDIT

Purchasing Decisions for an Interventional CT Program

Jonathan Troville, Ph.D.[1], Martin Wagner, Ph.D.[1,2], Lindsay Stratchko, D.O.[2], Giuseppe V. Toia, M.D.[1,2], Meghan G. Lubner, M.D.[2], Fred T. Lee, M.D.[2], Timothy P. Szczykutowicz, Ph.D.[1,2]

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Includes a book chapter covering scanner options in detail

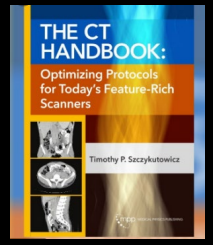
Interventional CT specific options

Scheduling

Table 17.1 A mapping of indications to scanner options. Note: this table deals only with scanner options; additional software packages may be needed to realize the listed indications. For example, to obtain a perfusion map, the scanner will need a perfusion acquisition mode and the data will need to be processed with a perfusion map creation software.

Indication/ Task	Perfusion	Cardiac Gating	Fluoroscopy	Respiratory Gating	MAR	Gantry Tilt	Wide Bore	Long Table	Wide Axial Collimation	Bariatric Table	Dual Energy	High-Power Tube[a]	Fast Scanning[b]	Extended FOV	Extended CT #	Flat Table
Brain perfusion	M	–	–	–	–	–	–	–	P	+	–	+	–	–	–	–
Brain multi-phase CTA	–	–	–	–	P	+	–	–	+	+	+	+	+	–	–	–
Abdominal organ perfusion	M	–	–	–	+	–	+	–	P	+	+	+	–	–	–	–
Lower extremity CTA	–	–	–	–	+	–	+	M	+	+	+	P	P	–	–	–
CTA/arterial imaging (+ surg. planning)	–	–	–	–	P	–	+	–	+	+	+	P	+	–	–	–
MSK	–	–	–	–	P	–	+	–	–	+	+	–	–	–	–	–
Spinal imaging with fixation hardware	–	–	–	–	M	–	+	–	–	+	+	–	–	–	–	–
Head & Neck with dental amalgam	–	–	–	–	P	P	+	–	+	+	+	+	+	–	–	–
Multiphase imaging	–	–	–	–	+	–	+	–	P	+	P	P	P	–	–	–
Trauma (MVC imaging)	–	–	–	–	P	+	+	P	+	P	+	M	P	P	–	–
Orthopedic surgery planning	–	–	–	–	P	P	+	–	–	+	+	–	–	+	–	–
Radiation therapy	–	–	–	M[c]	P	+	P	+	+	+	+	–	–	M	P	M
PE/triple rule out	–	–	–	–	+	–	+	+	P	+	P	P	P	+	–	–
Pediatric non-sedated	–	–	–	–	+	–	–	–	P	–	–	P	P	–	–	–
CTA chest	–	P	–	–	P	–	+	–	P	+	P	P	P	–	–	–
CTA coronaries	–	M	–	–	P	–	+	–	P	+	+	P	P	–	–	–
CT interventions	+[d]	–	M[e]	–	P	P	M	–	–	+	+	–	–	–	–	–
Virtual colonoscopy	–	–	–	–	+	–	+	–	+	+	–	+	+	–	–	–
Bariatrics	–	–	–	–	+	+	P	+	+	M	–	M	+	P	+	–

Szczykutowicz, Timothy. *The CT Handbook: Optimizing Protocols for Today's Feature-rich Scanners*. Medical Physics Publishing, 2020



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Scanner Features

CT Task Legend:
Green = CTF
Yellow = Diagnostics
Orange = Both

Work spearheaded at Wisconsin by Jonathan Troville, PhD
(presented at RSNA 2023 as an educational exhibit
"Purchasing decisions for an interventional CT program")

Highly Preferred

1) Wide Bore Access
2) Visualization Planes Along Needle
3) Gantry Ergonomics
4) In-Room Control
5) Gantry Tilt
6) Extended Table Option
7) Cardiac Gating
8) Neuro Perfusion

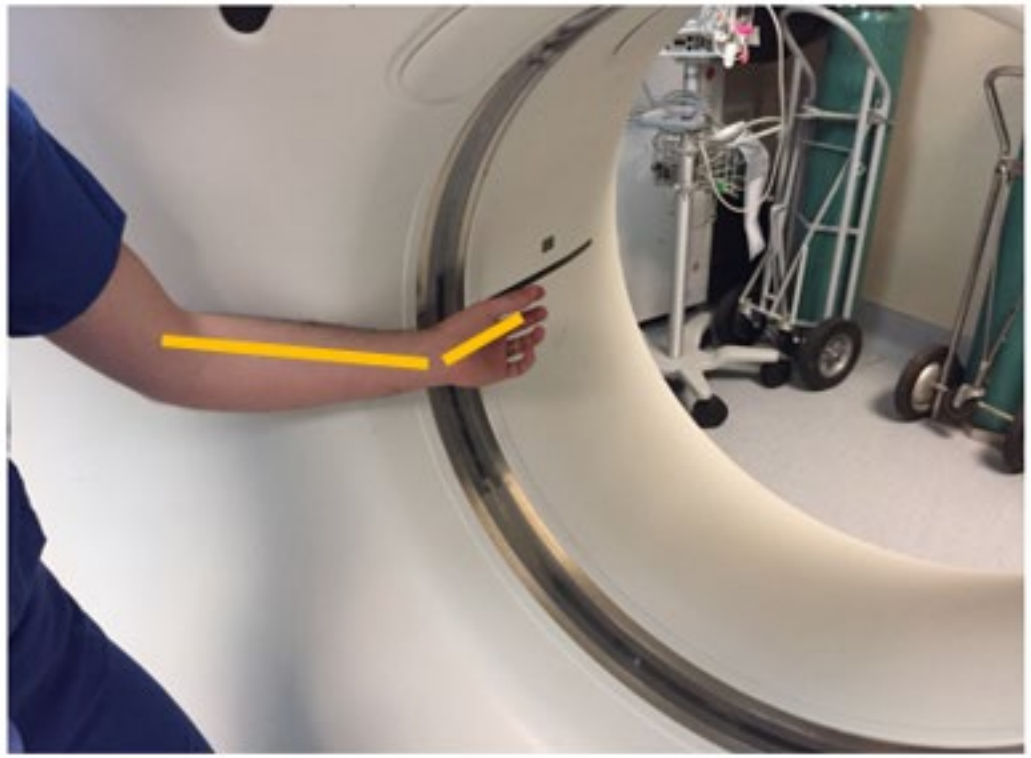
Preferred

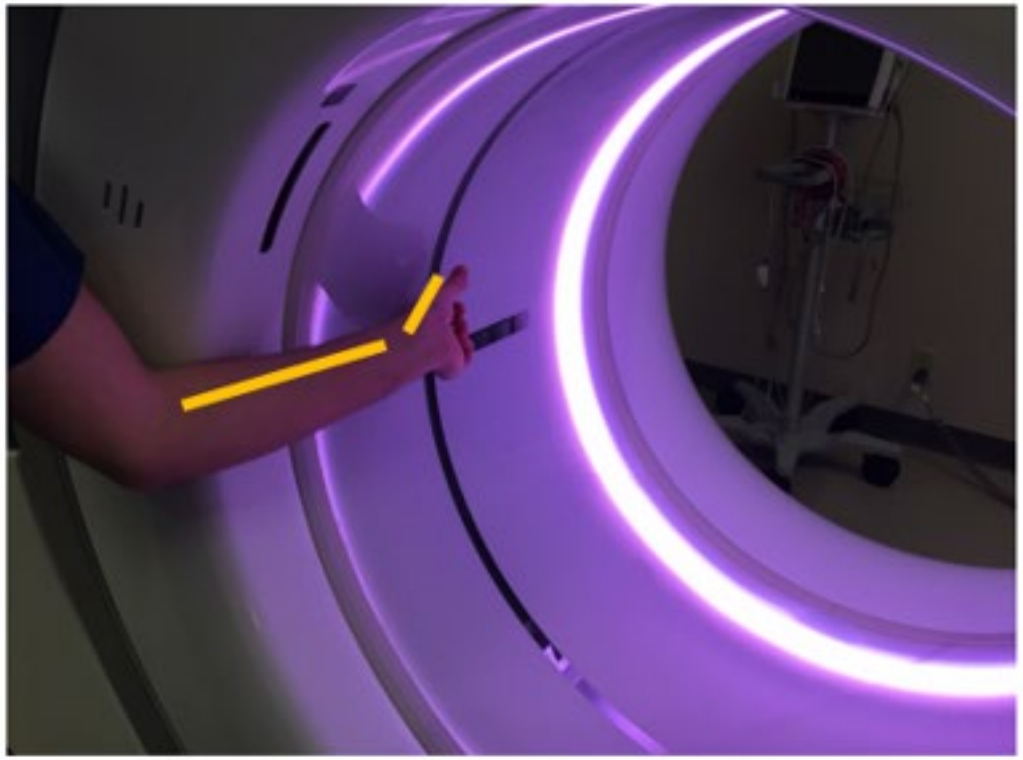
1) Prior Image Fusion
2) Needle Tracking/Trajectory Prediction
3) Bariatric Table
4) Tube Power Rating
5) Metal Artifact Reduction

Useful

1) Large Z-Axis Coverage
2) Dual Energy

Gantry Ergonomics





Wide Bore Access

We need at least enough room for device to fit!

Typical interventional “wide bore” CT scanners have openings 78-80 cm
Typical diagnostic scanner has a bore size of ~70 cm

Wide Bore Access

a) Physicians require ample space around patient for easy access to treatment sites and to manipulate devices without interference from CT gantry
b) Treatment of larger patients

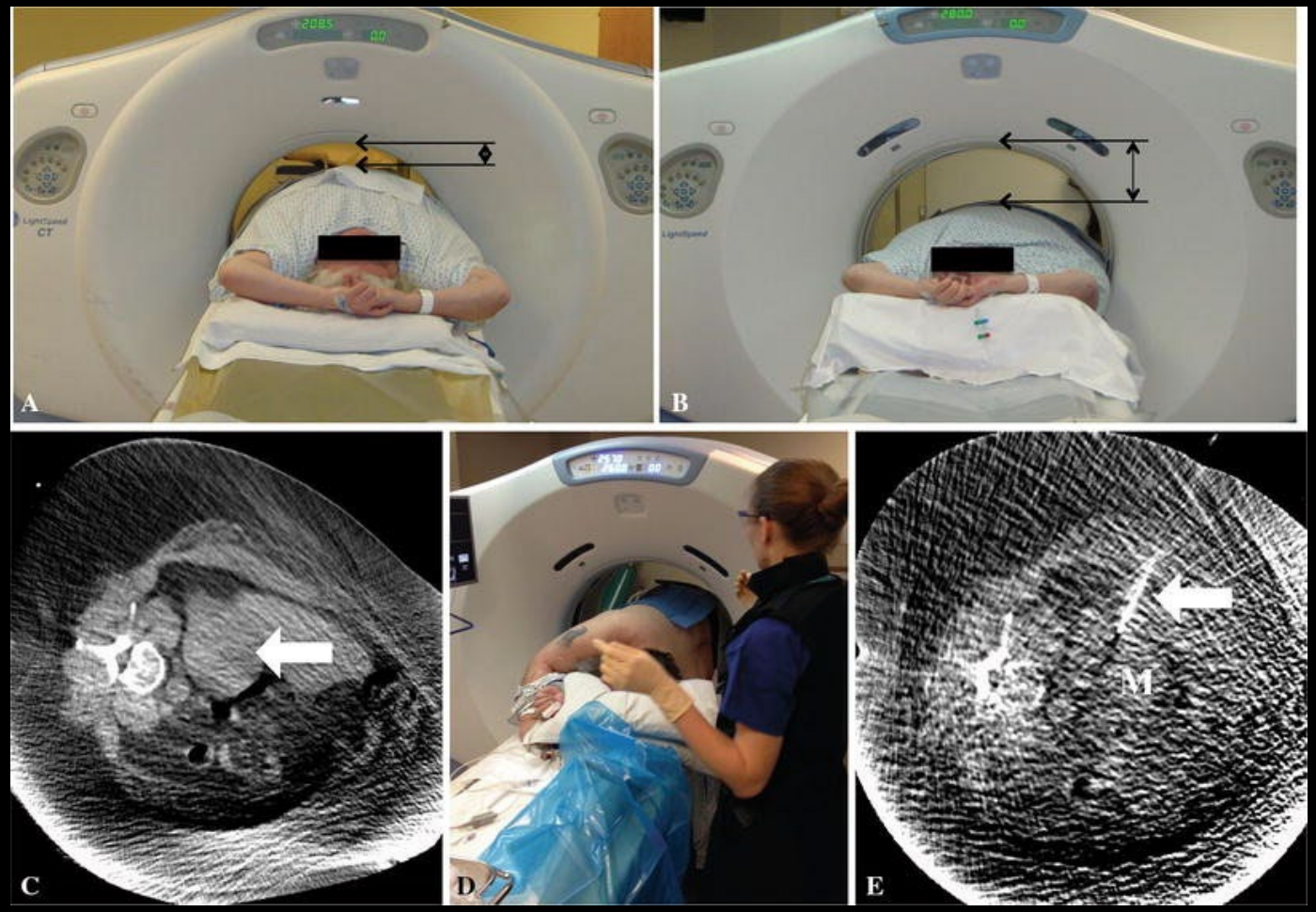


Figure obtained from: *Carberry, G. A., Lubner, M. G., Wells, S. A., & Hinshaw, J. L. (2016). Percutaneous biopsy in the abdomen and pelvis: a step-by-step approach. Abdominal Radiology, 41, 720-742.*

In Room Controls

a) Table-side controls can shorten procedure times and simplify the process of needle guidance (i.e., not leaving the room to acquire an image to then adjust the needle or rely on the physician to communicate acquisition and image display instructions to a technologist).

Figure Acquired From: *Troville, J., Wagner, M., Stratchko, L., Toia, G.V., Lubner, M.G., Lee, F.T., & Szczykutowicz, T.P. (2023). Purchasing Decisions for an Interventional CT Program. Radiology Management, v45 n3, 23-29.*

Gantry Tilt

Szczykutowicz, Timothy. *The CT Handbook: Optimizing Protocols for Today's Feature-rich Scanners*. Medical Physics Publishing, 2020

Gantry Tilt

Gantry tilt is really one of the game changing options for head and neck diagnostic imaging to mitigate metal artifacts.

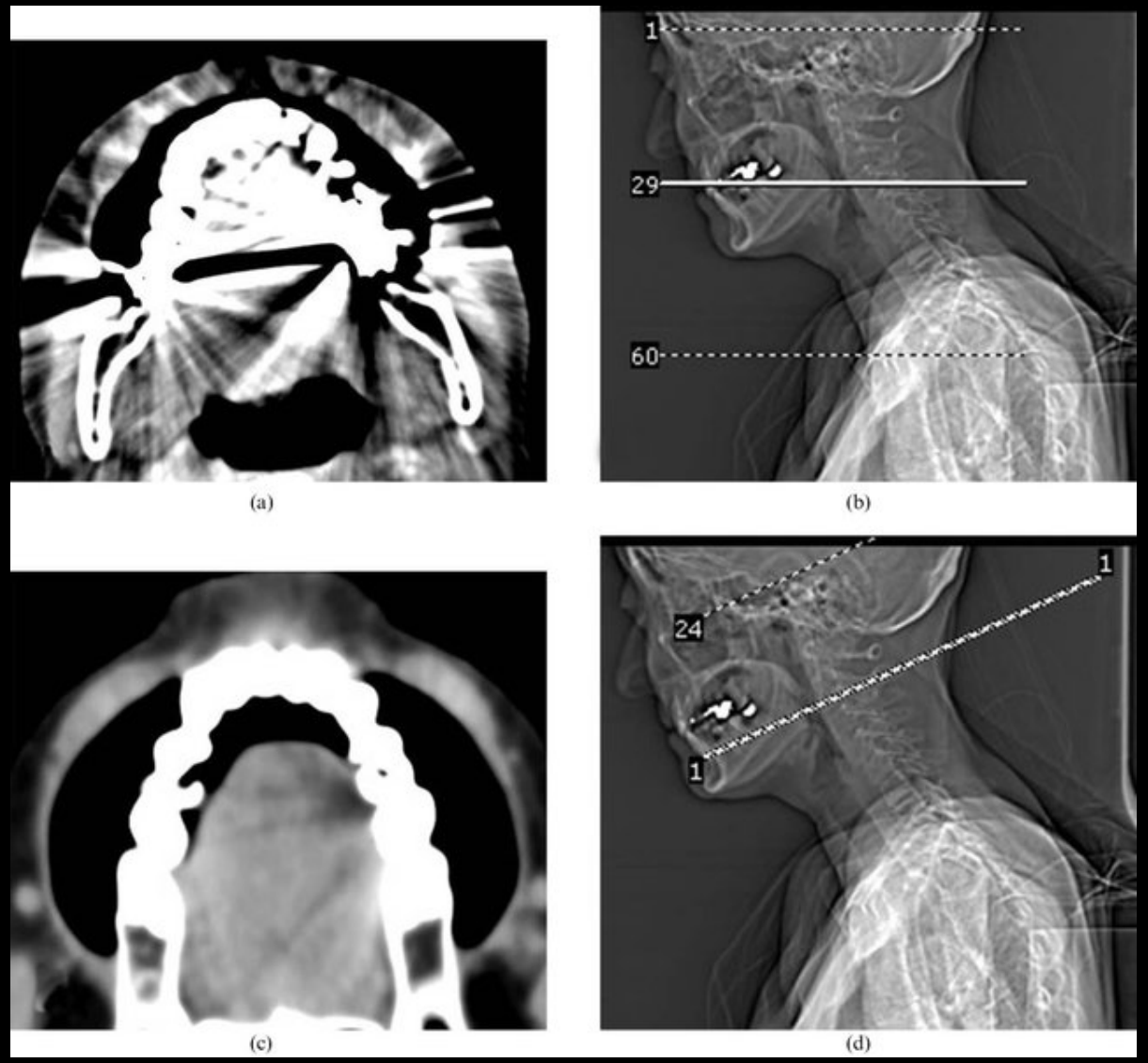
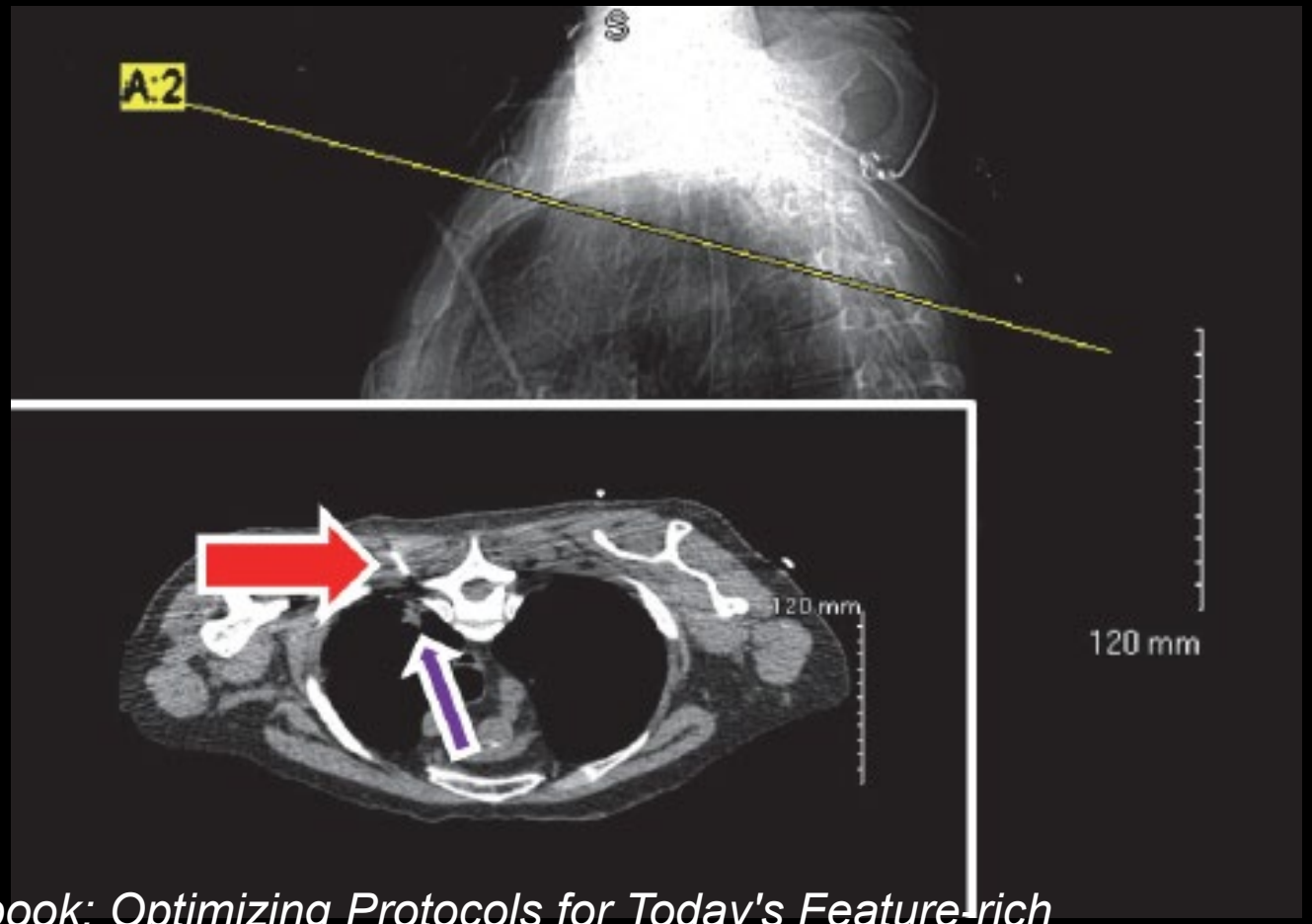


Figure Acquired From: *Law, C. P., Chandra, R. V., Hoang, J. K., & Phal, P. M. (2011). Imaging the oral cavity: key concepts for the radiologist. The British Journal of Radiology, 84(1006), 944-957.*

Gantry Tilt

In interventional CT, gantry tilt is used to puncture the lung at a ~90-degree angle, or to allow for better patient access (around the CT gantry)



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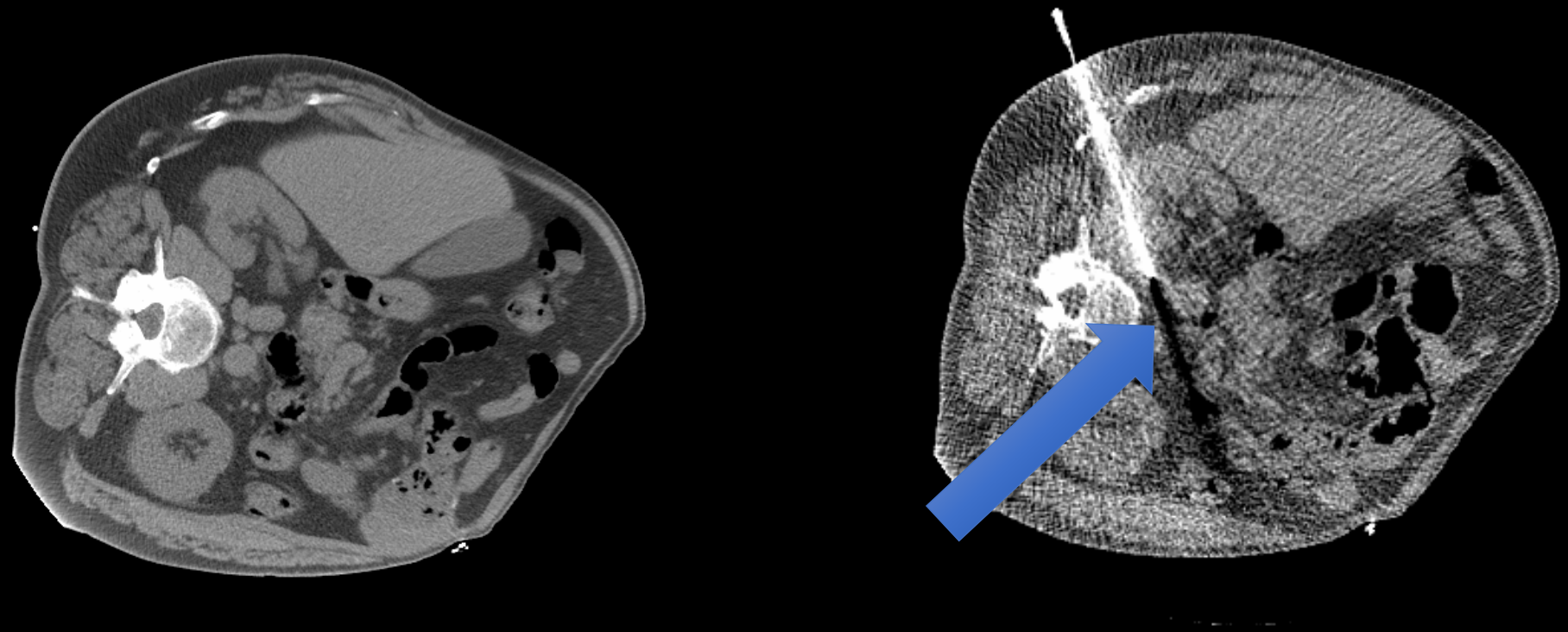
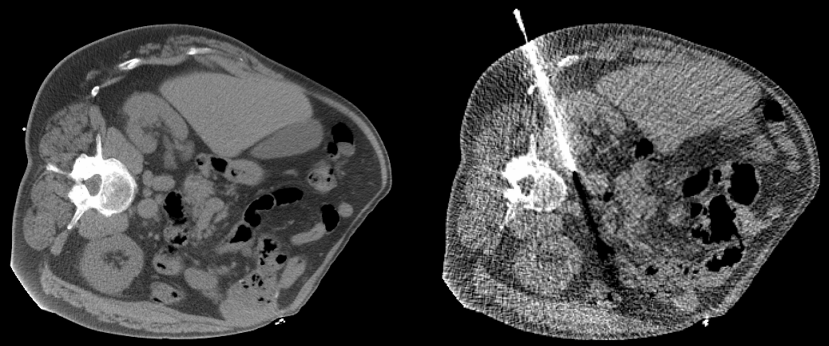
Metal Artifact Reduction



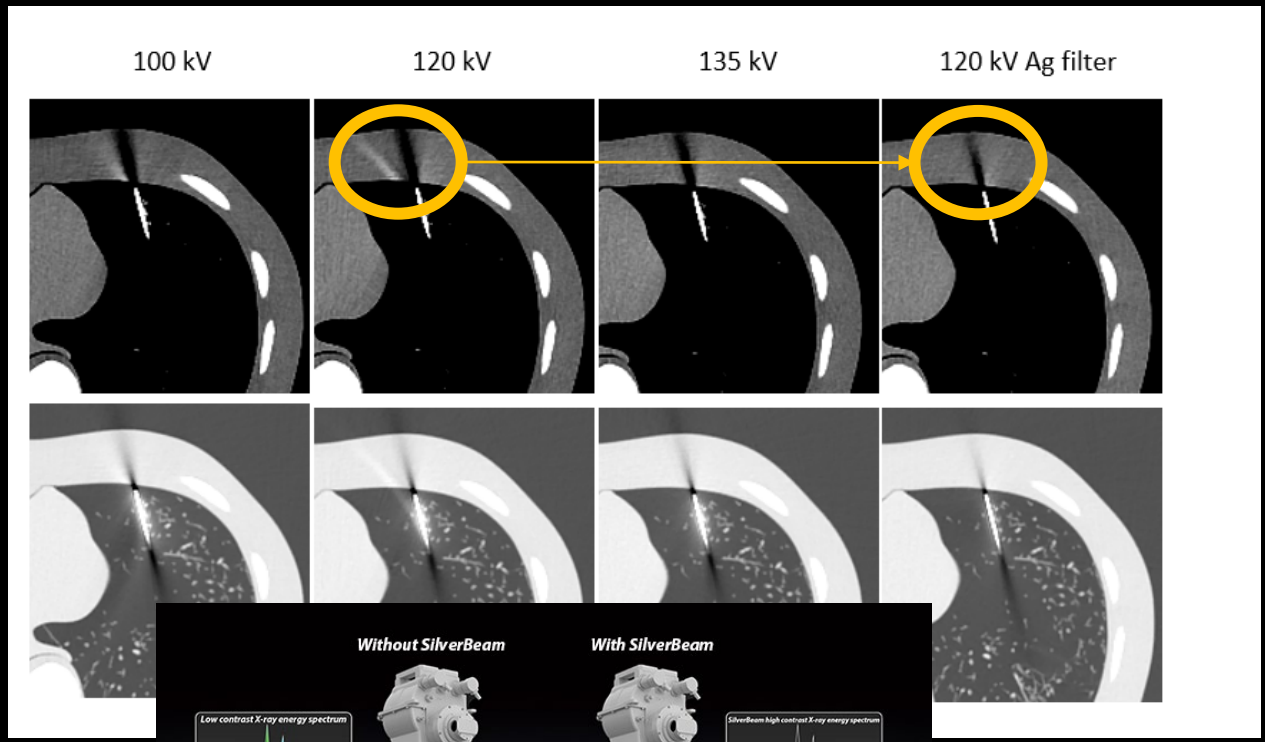
Metal artifacts in interventional CT literally put blinders on the physician in the exact spot they most need to see

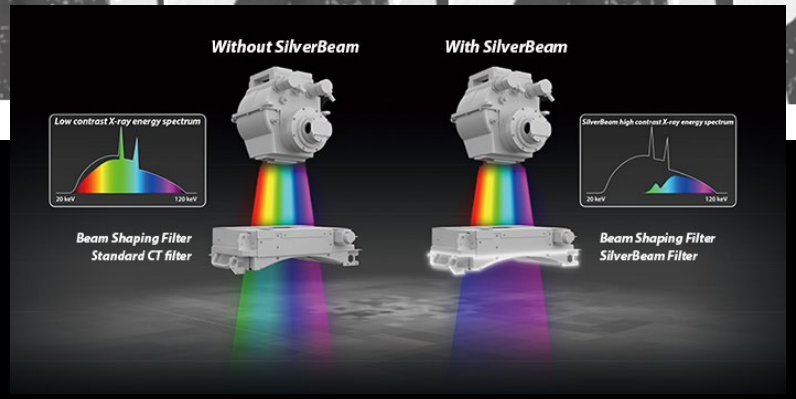
Metal Artifact Reduction



Interventional CT needs to have near real time imaging, MAR algorithms are too slow for this.

Currently no vendors offer MAR algorithms in interventional CT modes. Canon does offer Ag beam filtration, which does partially reduce metal artifacts.





Title: Needle artifact reduction during interventional CT procedures using a silver filter

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Keywords: Interventional CT, CT artifact, CT filter

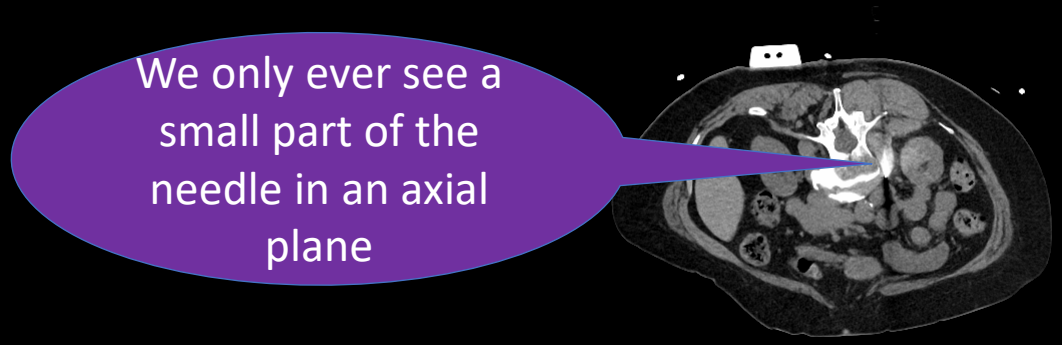
Visualization Planes Along Needle

Data in CT is only acquired in the axial scanner plane

Devices can be inserted into the patient at planes other than the scanner's axial plane

Needle is inserted along scanner's axial plane

Needle is not inserted along scanner's axial plane



Visualization Planes Along Needle

A CT scanner can allow the user to manually, or automatically create oblique reformatted views which are aligned to the axis of the needle. This lets the physics see “in front of” the needle.

Visualization Planes Along Needle

These images were all taken at the same time, I am just scrolling through slices. See how difficult it is to see the trajectory of the needle when it is not aligned with the imaging plane!

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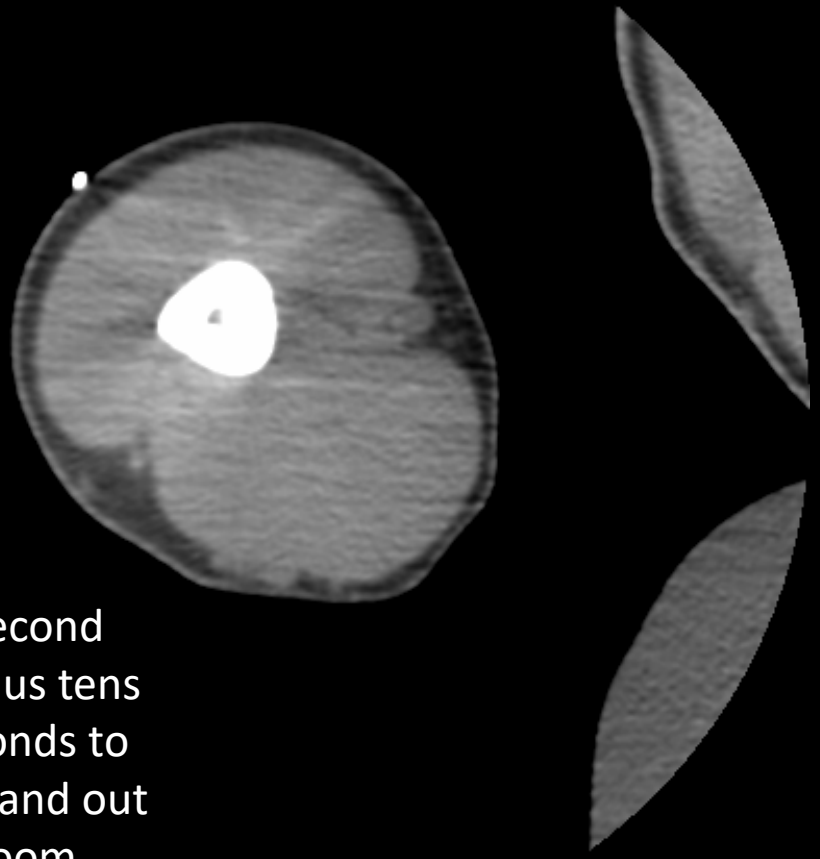
Fluoroscopy Options

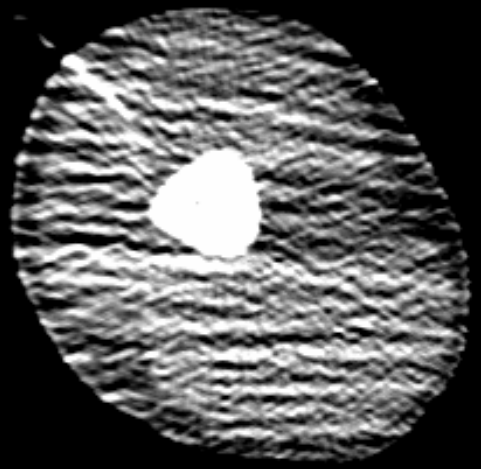
Interventional imaging should not use **diagnostic doses**! The walk in and out of the room and use of a dx protocol to localize interventional devices is decades old workflow (Haaga 1976 Radiology).

Interventional Imaging Dose

68 mGy

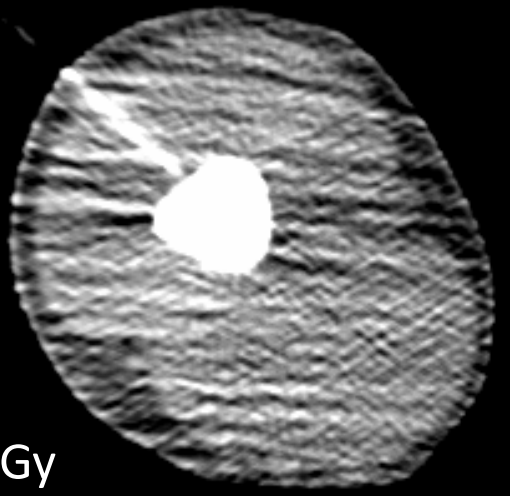


3.6 second scan, plus tens of seconds to walk in and out of room



1.59 mGy

0.5 second scans



3.19 mGy

Fluoroscopy Concepts

- Increases in dose rate increase physician scatter
  - I.E., generating more x-rays allows more scattering
- Increases in collimated beam area increase scatter
  - I.E., the large the patient volume irradiated, the more scattered x-rays
- Scatter is always higher where x-rays enter the patient
  - True for c-arms AND Computed Tomography

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Laboratory Investigation

CT Fluoroscopy for Image-Guided Procedures: Physician Radiation Dose During Full-Rotation and Partial-Angle CT Scanning

Emily A. Knott BS [a], Sean D. Rose PhD [b], Martin G. Wagner PhD [b], Fred T. Lee Jr. MD [a], Jeff Radtke MS [b], Daniel R. Anderson MS [b], Annie M. Zlevor BA [a], Meghan G. Lubner MD [a], J. Louis Hinshaw MD [a], Timothy P. Szczykutowicz PhD [a, b, c]

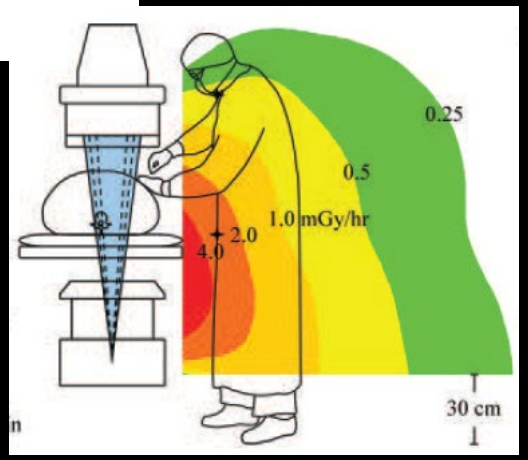
RSNA Education Exhibits

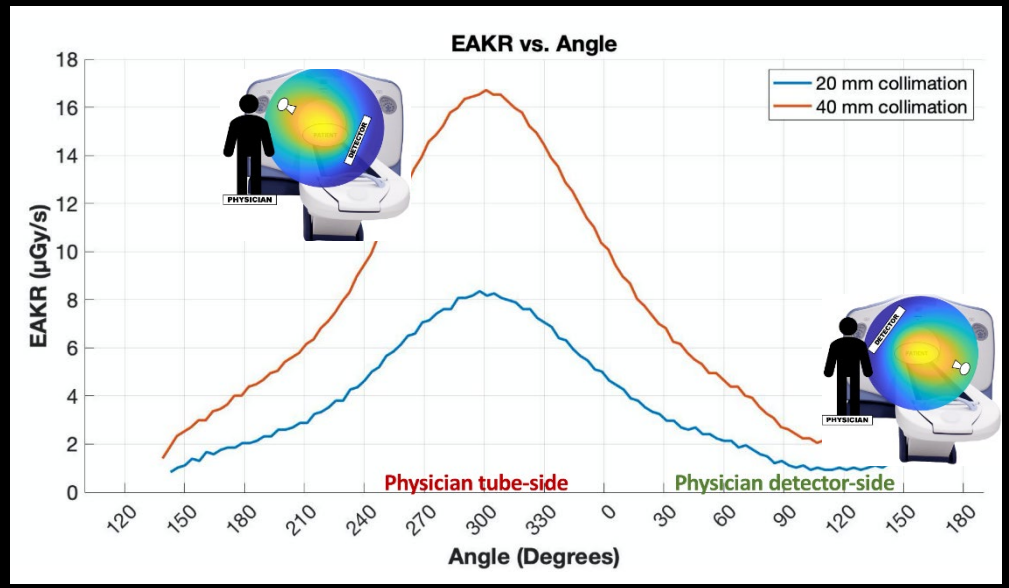
An Investigation of Operator Exposure in Interventional Radiology

Beth A. Schueler, Thomas J. Vrieze, Haraldur Bjarnason, Anthony W. Stanson

Author Affiliations

Published Online: Sep 1 2006 | https://doi.org/10.1148/rg.265055127





Fluoroscopy Dose

C-Arm vs CT Fluoroscopy: Dose Metric Comparisons		
	C-Arm	CT
Entrance absorbed dose rate (mGy/s)	0.2	3.0
Exposed area at skin surface (cm^2)	112	24
Absorbed dose area product rate ($mGy*cm^2/s$)	22	72
Mean Fluoroscopy Time (sec)*	710	23
Absorbed dose area product ($mGy*m^2$)	1.59	0.17

Summary:

The cumulative absorbed dose area product is ~9.4 times lower for CT compared to C-Arm procedures, thus we expect a similar relative proportion for occupational dose

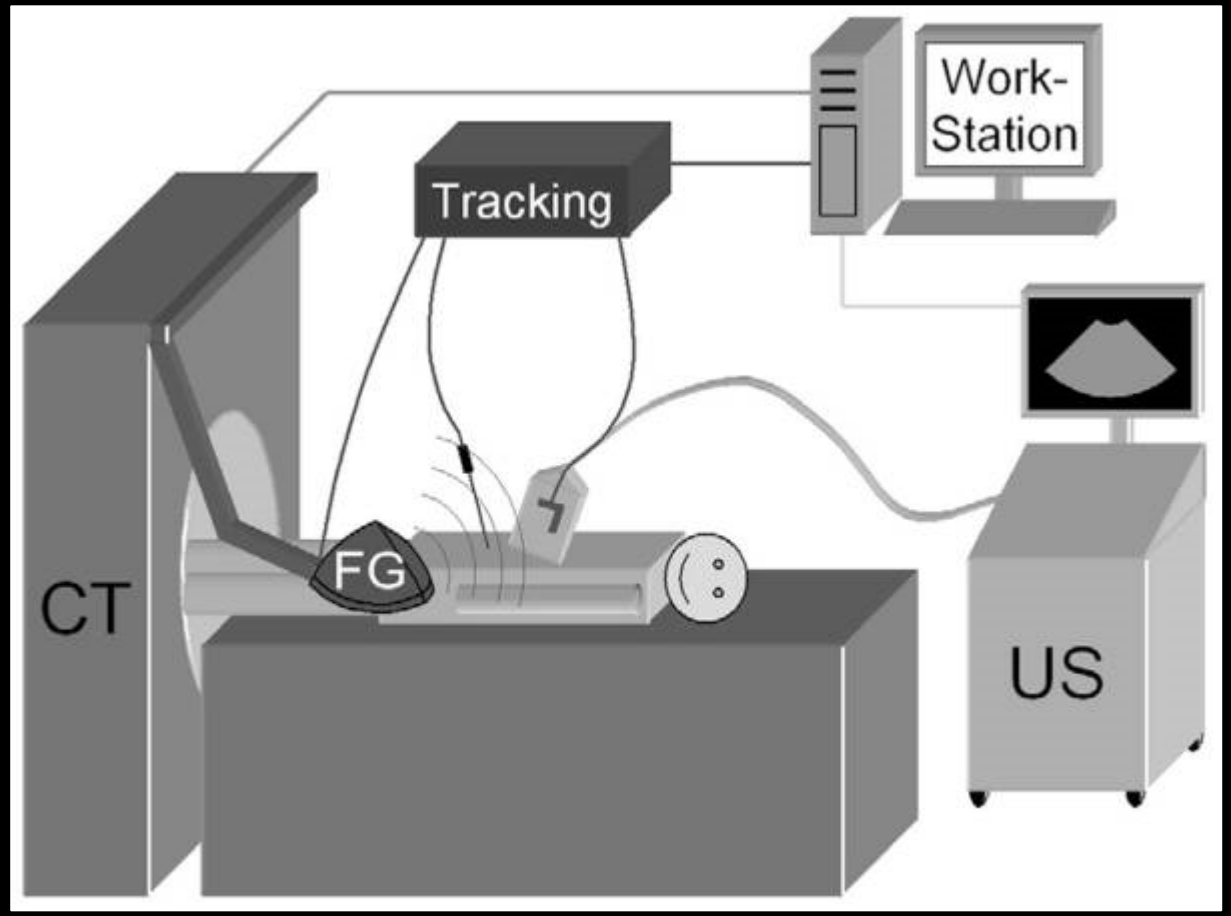
While one may expect a larger amount of scatter dose from CT procedures given the significantly larger dose rate, the 31x lower fluoroscopy time and 4.7x lower beam area lead to a much lower scatter dose when compared to C-Arm procedures

*a) Data not yet published (E. Knott et al (2022))
b) acquired from 1722 CTF procedures including ablations, drainages, aspirations, biopsies, spinal nerve root blocks, and sacroiliac injections

Outline

1. What is Interventional CT?
2. High level scheduling considerations
3. Scanner Options Overview
4. Interventional CT Specific Options
5. Dose
6. **Advanced Device Guidance**
7. Ongoing Research

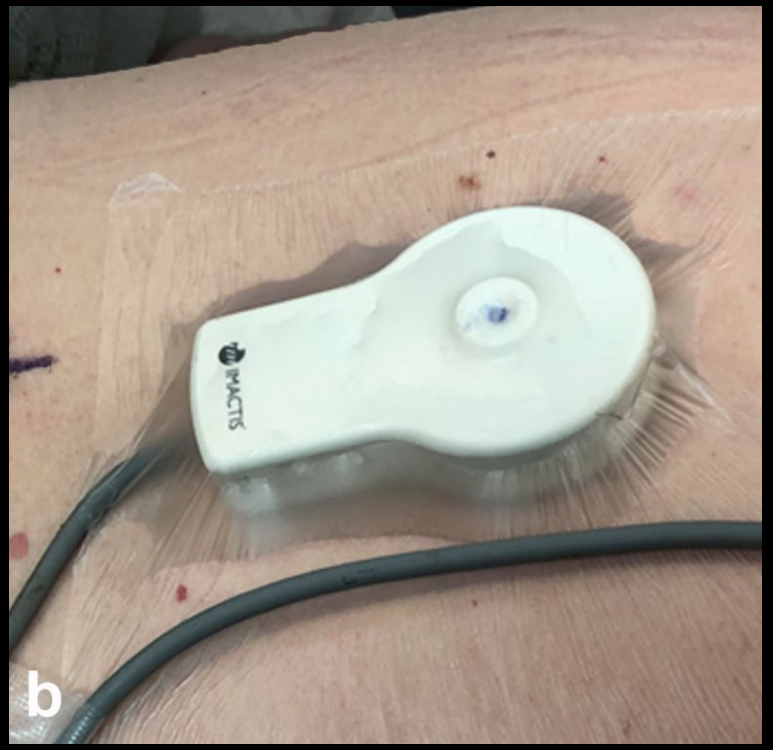
Advanced Guidance: EM Tracking



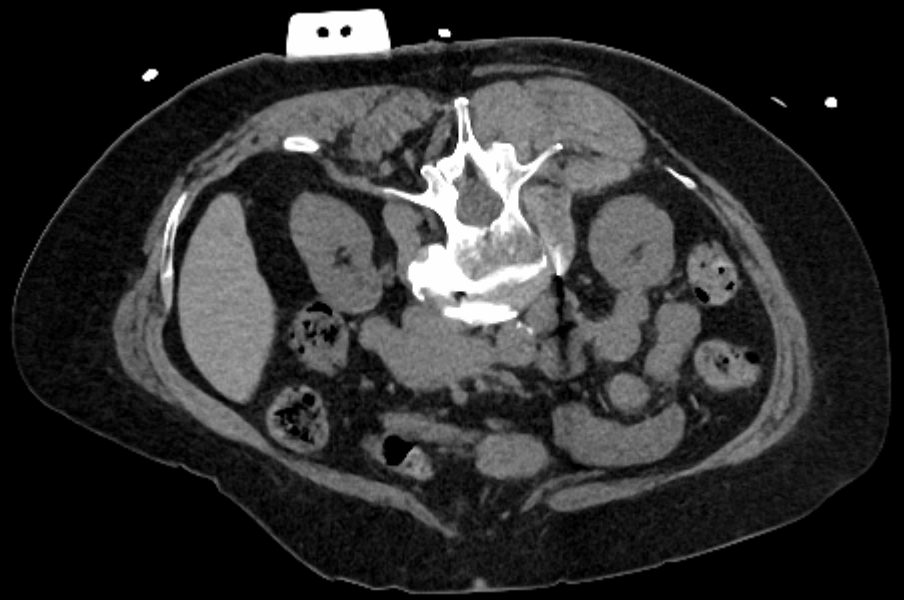
Krücker, J., Xu, S., Glossop, N., Viswanathan, A., Borgert, J., Schulz, H., Wood, B.J., 2007. J. Vasc. Interv. Radiol. JVIR 18, 1141–1150.

Advanced Guidance: EM Tracking

Zlevor, A.M et al., 2023. J. Vasc. Interv. Radiol. 34, 910–918.



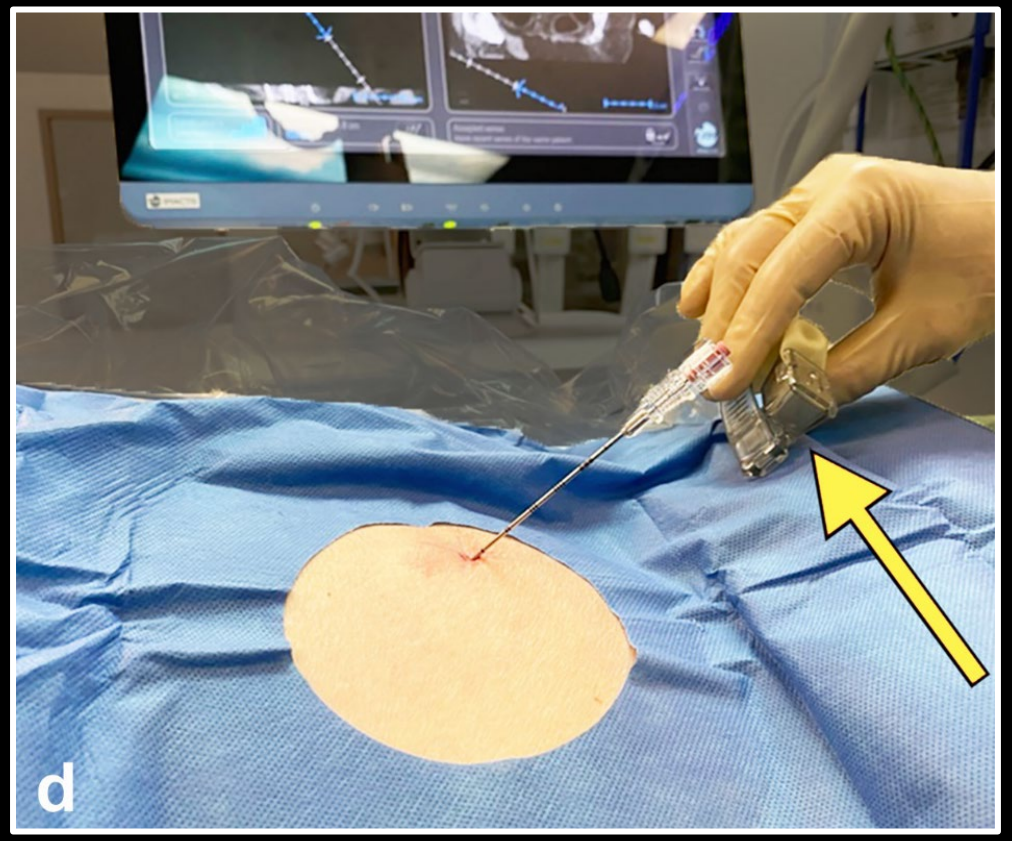
1. EM field generator is attached to patient skin



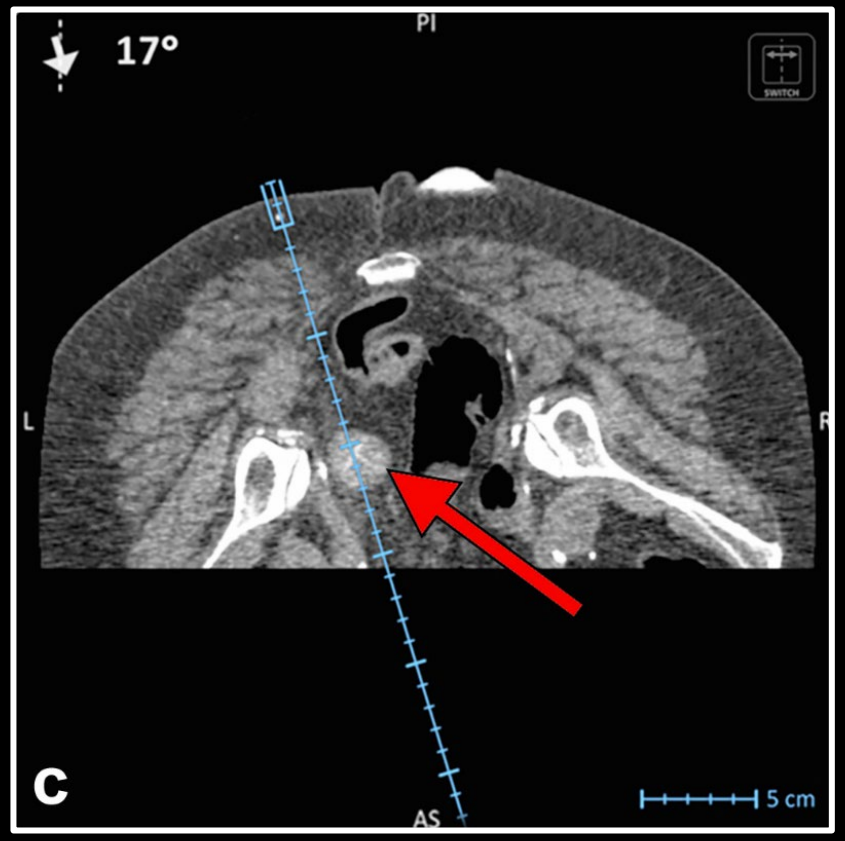
2. CT scan of patient and EM field generator registers the system to CT

Advanced Guidance: EM Tracking

Zlevor, A.M et al., 2023. J. Vasc. Interv. Radiol. 34, 910–918.

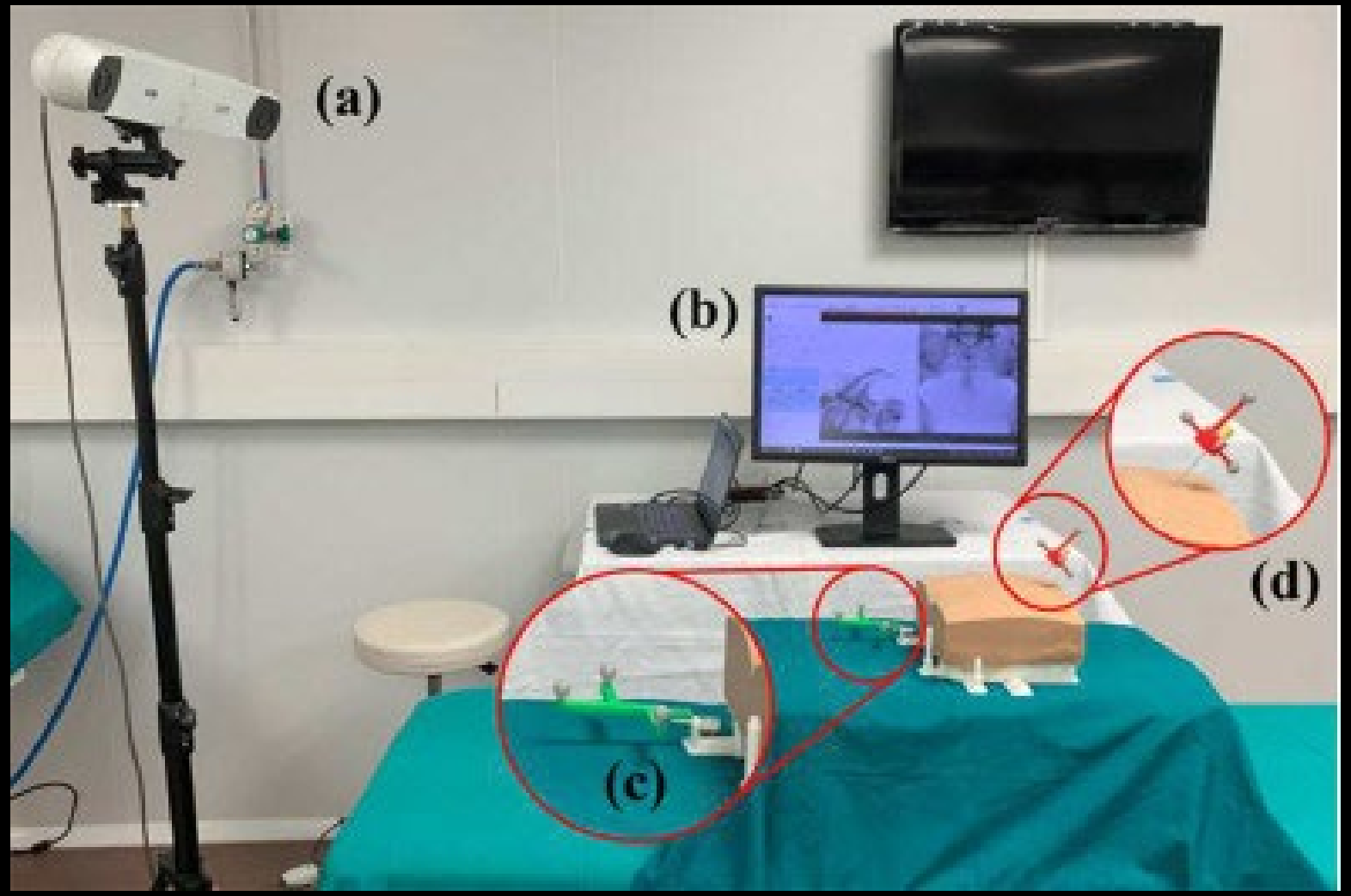


3. EM sensor attached to the needle holder provides real-time needle position



4. Virtual needle position and trajectory is superimposed on CT

Optical Tracking



Moreta-Martínez, R., Rubio-Pérez, I., García-Sevilla, M., García-Elcano, L., Pascau, J., 2022. Comput. Methods Programs Biomed. 224, 106991.

Robotic Needle Guidance

Ben-David, E., Shochat, M., Roth, I., Nissenbaum, I., Sosna, J., Goldberg, S.N., 2018. J. Vasc. Interv. Radiol. JVIR 29, 1440–1446.

Scharll, Y., Mitteregger, A., Laimer, G., Schwabl, C., Schullian, P., Bale, R., 2022. J. Clin. Med. 11, 3746.

Outline

1. What is Interventional CT?
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4. Interventional CT Specific Options
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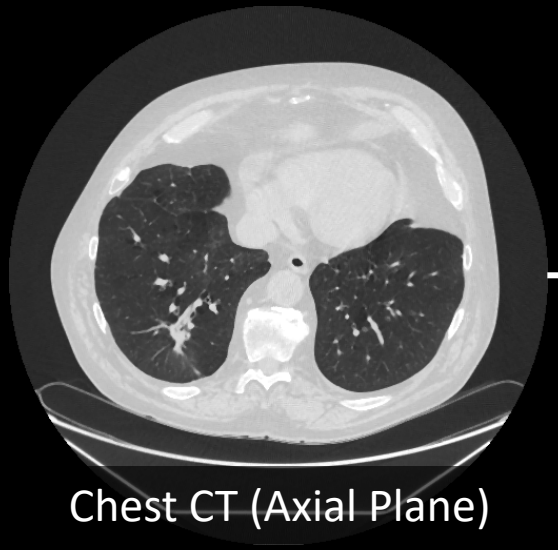
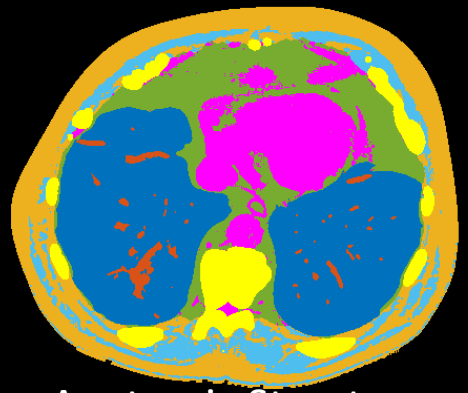
7. **Ongoing Research**

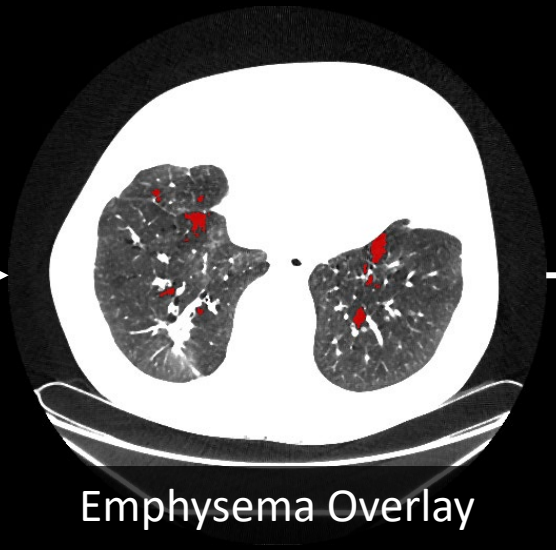
Algorithm Overview



Chest CT (Axial Plane)

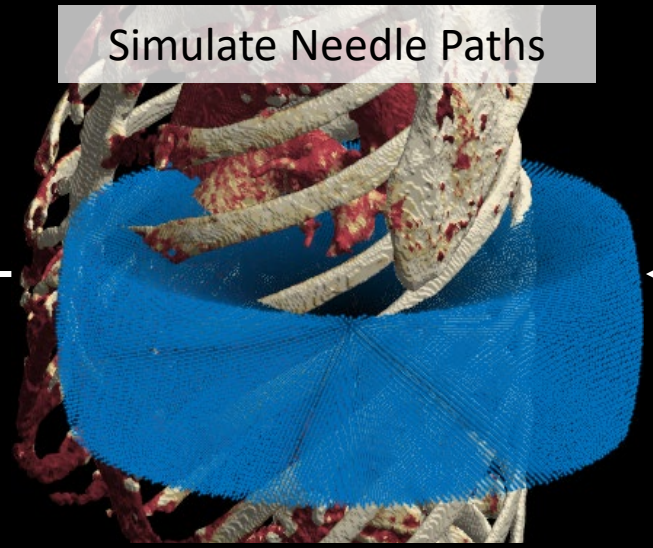


Anatomic Structure Segmentation

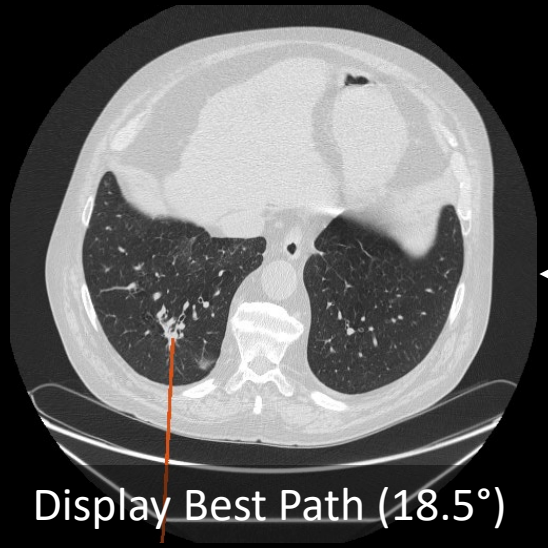


Emphysema Overlay

Simulate Needle Paths



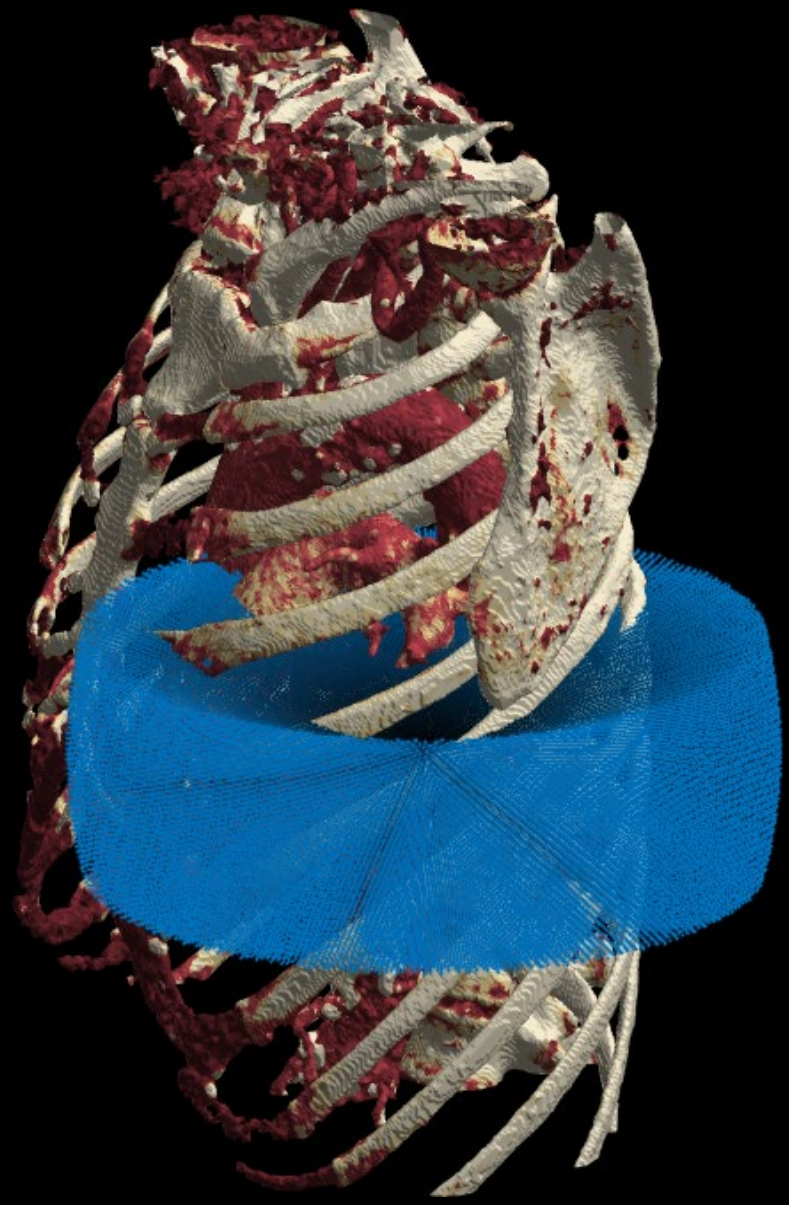
Path evaluation based on traversed tissue and pre-written rules



Display Best Path (18.5°)

Needle Path Simulation

- An artificial intelligence (AI) algorithm can consider many pathways (50,000) out of plane
- Segmentation determines which tissues are traversed
- Calculates “risk” based on a pre-written set of rules to suggest the safest pathway



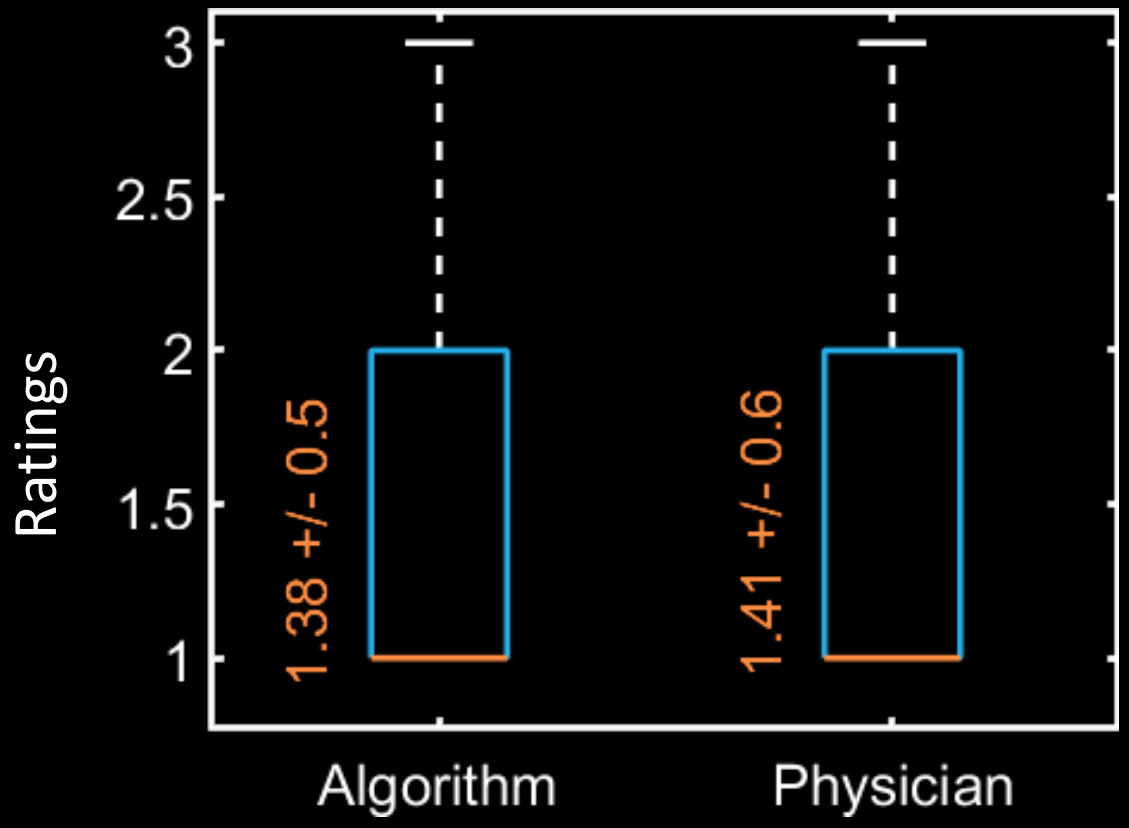
Scoring System

Category	Structure or organ	Metric	Weight	Minimum ranking
Path is crossing critical structures or organs (yes = 1, no = 0)	Heart/aorta	Yes/no	Infinity	5
	Large vessels or airways	Radius ≥ 1.5 mm	1	3
	Other organs	Yes/no	3	4
	Fissure	Yes/no	0.6	4
	Emphysematous bleb	Radius ≥ 2 mm	0.8	4
	Ribs or bone	Yes/no	3	4
	Spine	Yes/no	Infinity	5
Path is close to critical organs	Heart	(10 mm to minimum distance)/10 mm	0.8	NA
	Large vessels or airways	(10 mm to minimum distance)/10 mm	0.8	NA
Trajectory angle	Angle (±90°) to axial plane	Abs (angle/90)	0.05	NA
	Angle (0°–90°) to pleural surface	(90 − angle)/90	0.25	3 if metric > 0.7
Length of needle path	Path length (mm) through lung tissue (at least 1 cm)	Maximum (0 [10 mm − length]/10 mm)	0.5	NA
	Total path length (mm) through tissue	Maximum (0 [length−60 mm]/40 mm)	1	3 if metric > 100
	Path length through minor vessels or airways	0.5 × length	1	NA

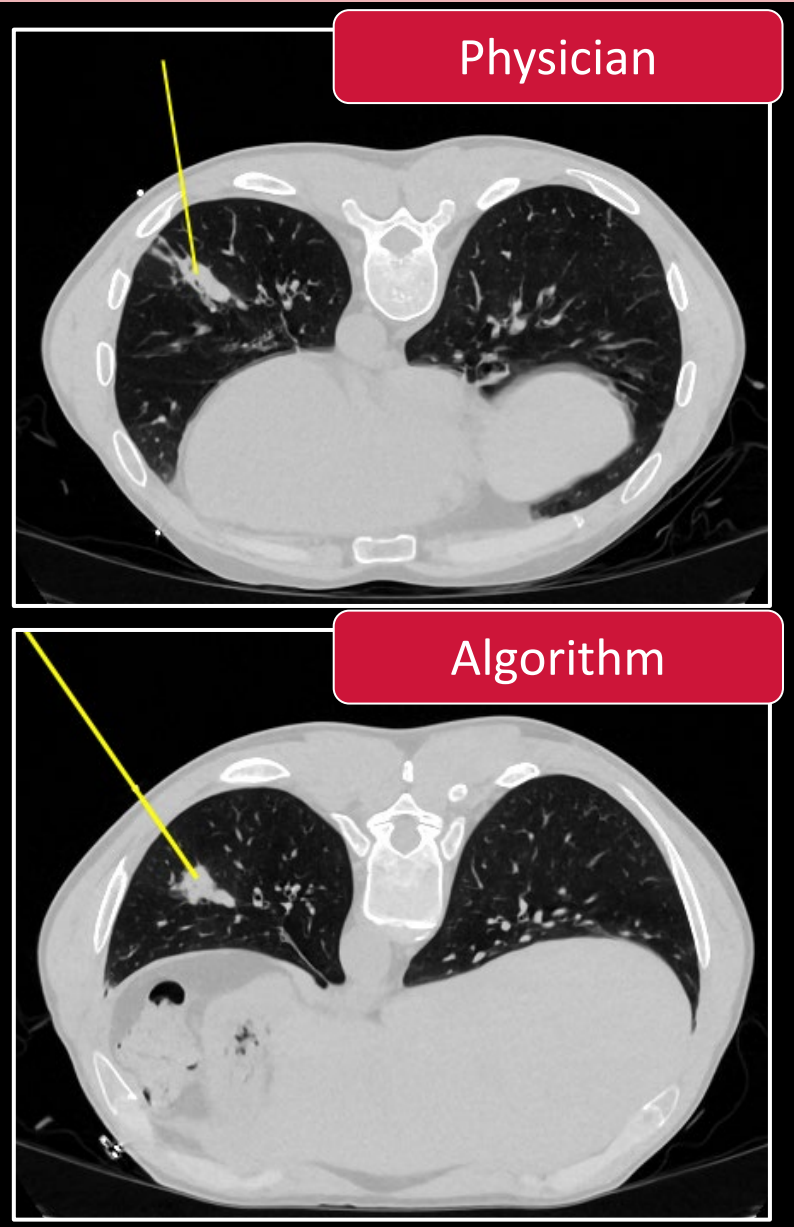
- Rules-based approach
- Based on physician feedback
- Weights can be manually adjusted or “learned” over time

[1] **M. A. Kisting** *et al.*, *J Vasc Interv Radiol*, Nov. 2023, doi: 10.1016/j.jvir.2023.11.016.

Results Overview

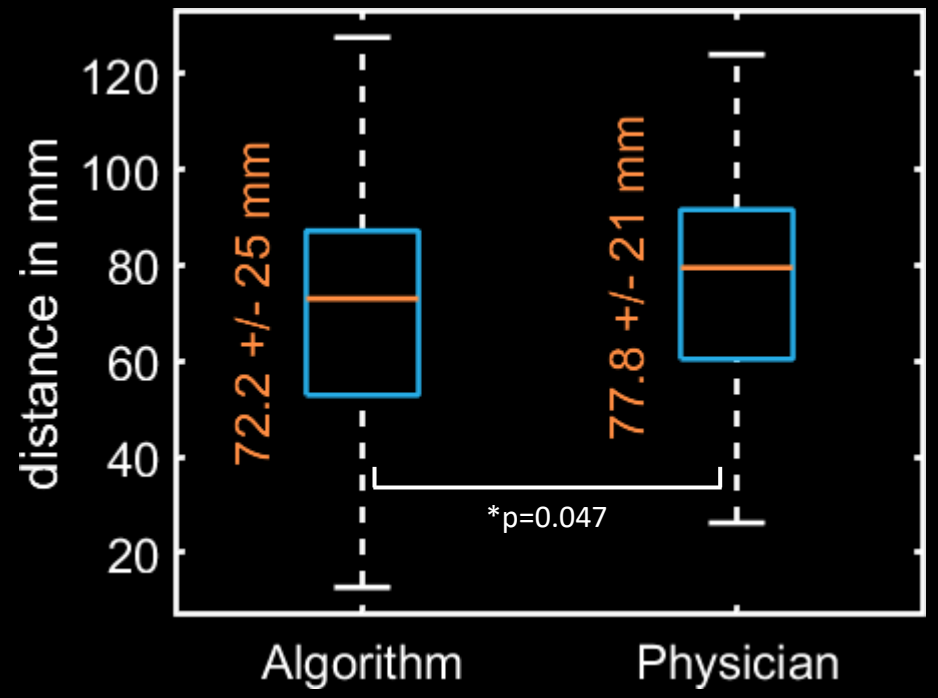


two-sided Wilcoxon signed rank test: p=0.6

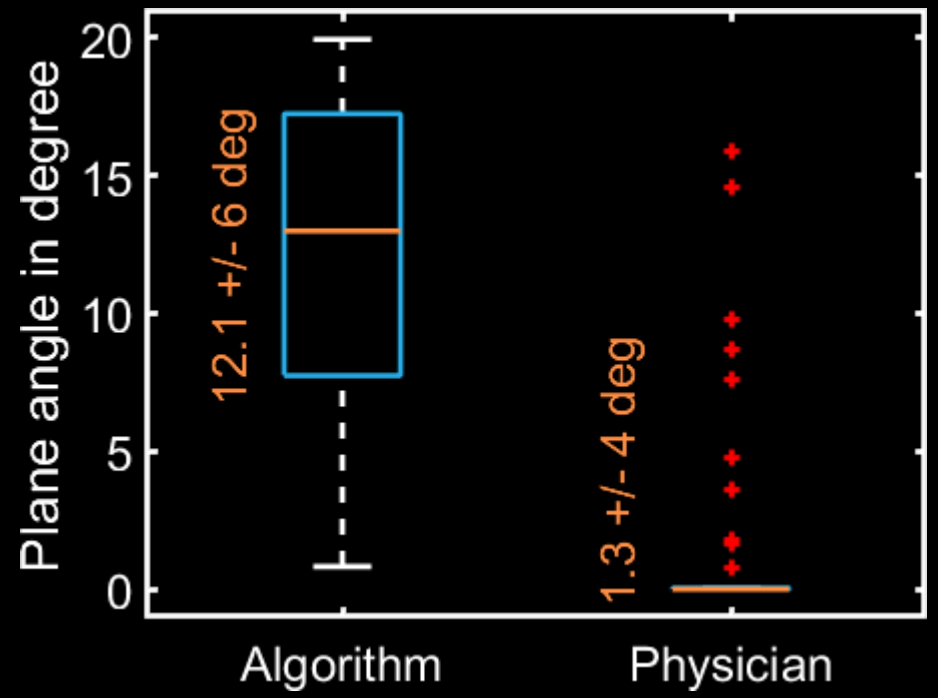


Objective Quantitative Metrics

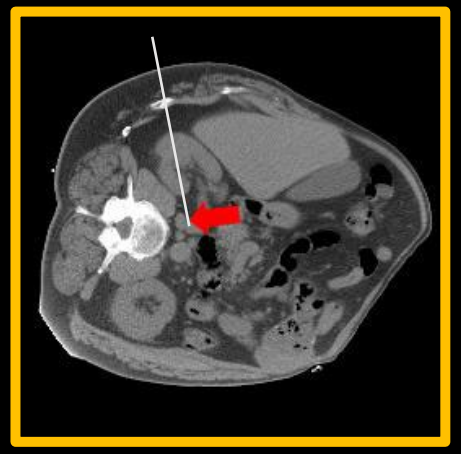
Skin to target distance



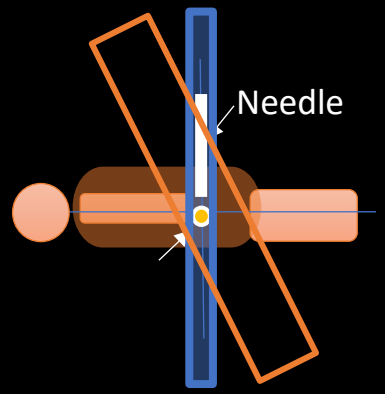
Angle between path and axial plane



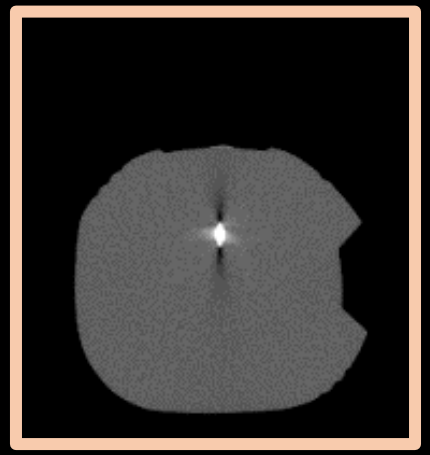
Needle-ART Method Overview



1. Plan needle trajectory

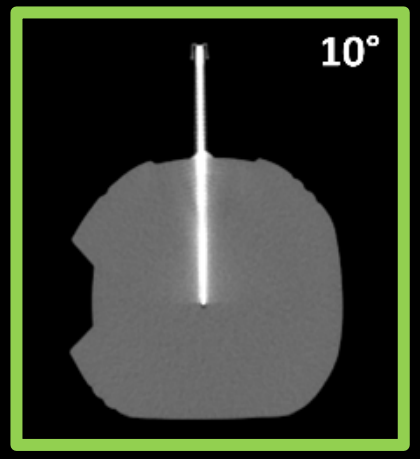


2. Place / update needle and tilt gantry



3. Acquire axial scan with gantry tilt

4. Automatic Segmentation of Needle Centerline

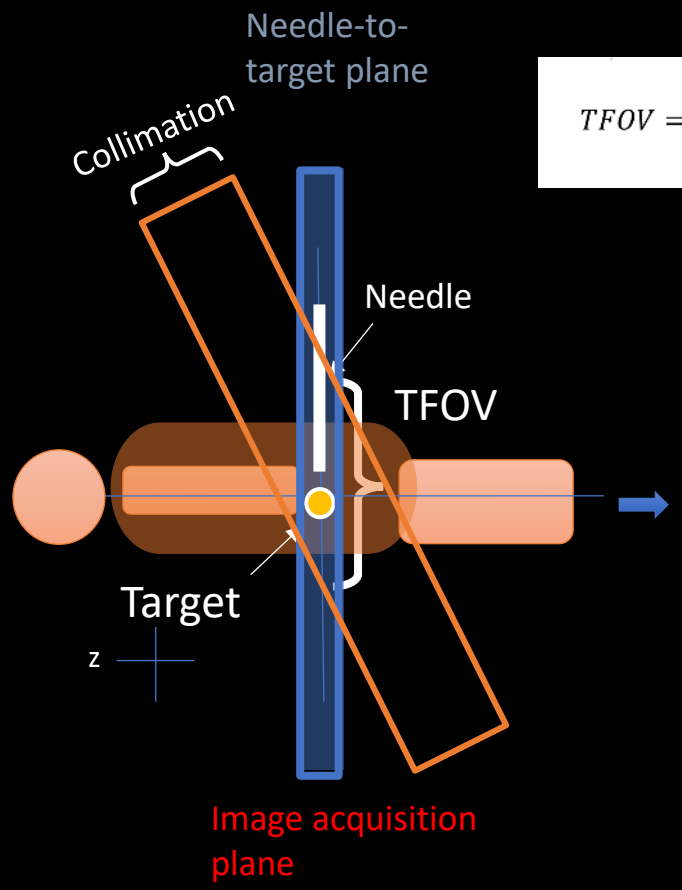


5. Reformat image to needle plane

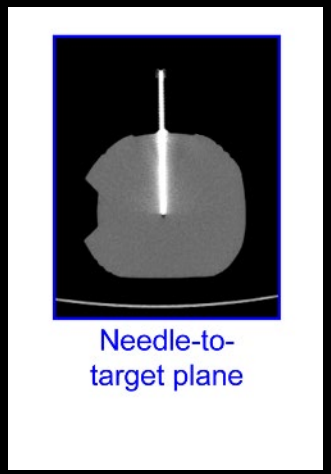
Needle-ART

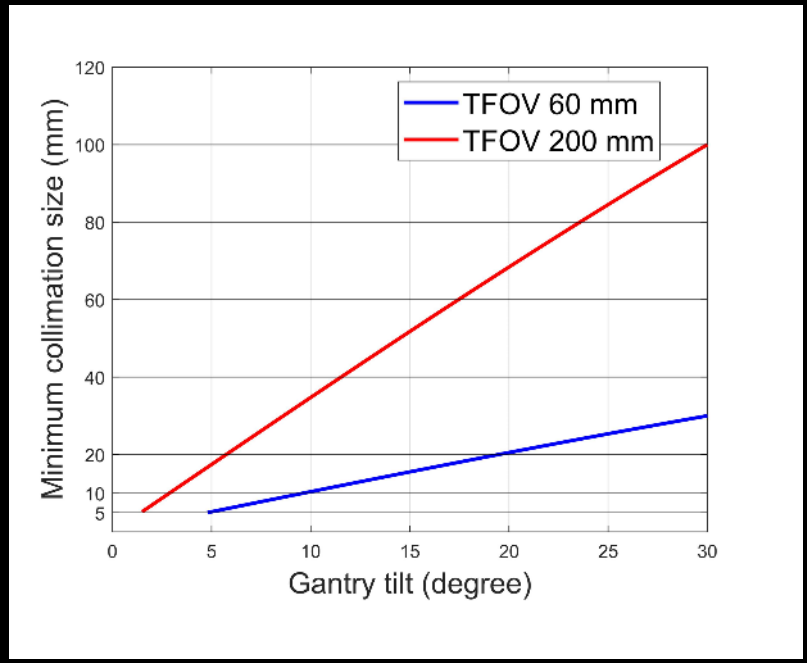
TFOV ↑ Collimation size ↑

TFOV ↓ Gantry tilt ↑



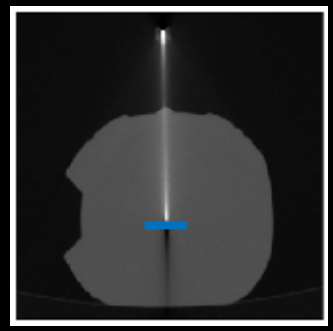
$$TFOV = \frac{collimation\ size}{\sin(gantry\ tilt\ angle)}$$





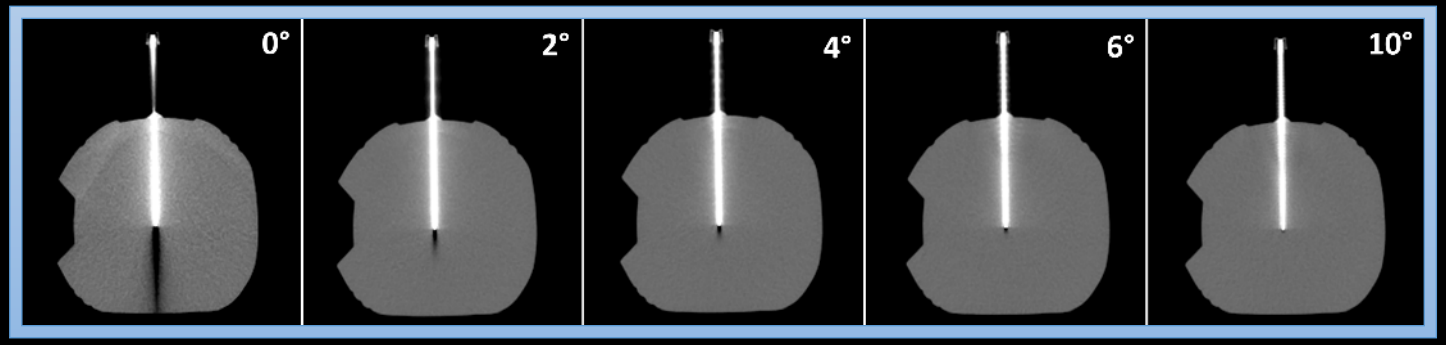
Results

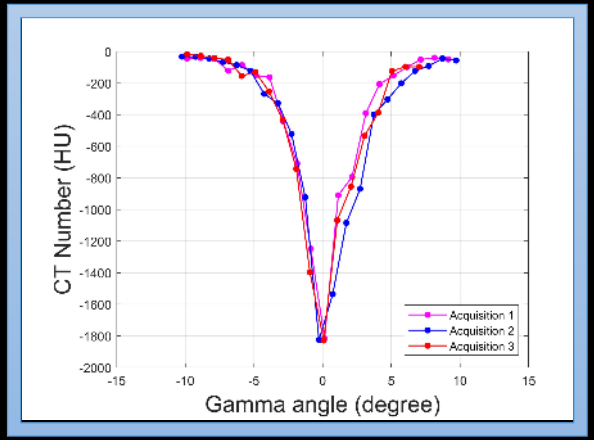
Perpendicular profile to the trajectory artifact



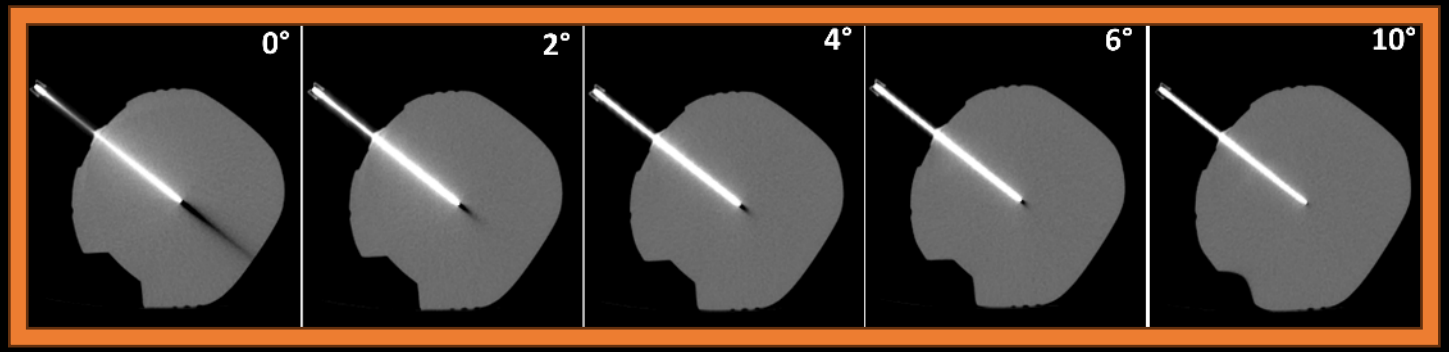
Water gallon phantom

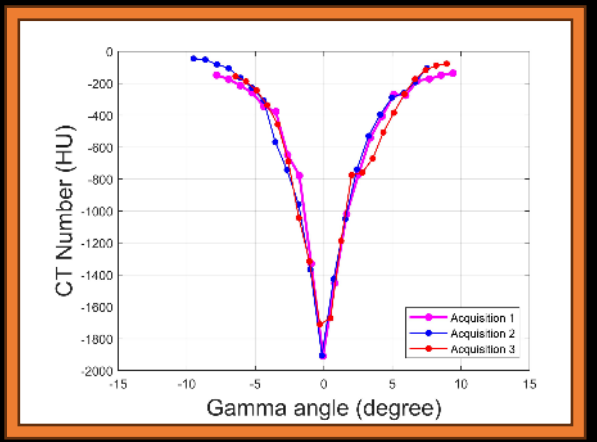
0° →





45° →





Thank You